Monitoring physiological responses to training and match play in adolescent footballers.

Jack Ferguson

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Research Thesis Submission

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Abstract

Introduction: Recently, there has been a growing interest into the monitoring of training and match load and subsequent physiological responses adolescent footballers experience (Malone, 2014). Before a physical performance test can used as a monitoring tool, its reliability must be quantified (Thorpe et al., 2015). Therefore, the aims of this thesis are two-fold: 1) quantify the reliability of a number of physical performance tests and 2) using the same physical performance tests quantify physiological responses to load over acute and chronic training periods.

Methodogly: First the reliability of eccentric hamstring strength, isometric adductor strength and linear sprint tests were quantified, in a cohort of adolescent footballers (n = 37). Secondly training and match load was recorded over a 4-week period in another group of adolescent footballers (n = 10). Measures of lower body strength and speed were recorded prior to the start of every training session and match.

Results: Acceptable levels of reliability were found for at least one metric of the three physical performance tests. An increase greater than the typical error of the test in eccentric hamstring strength was found after a 4-week training period but despite variations in load, no changes in lower body strength and speed were recorded between training sessions and matches.

Discussion: Eccentric hamstring strength, long lever isometric adductor strength and 30-metre sprint performance are reliable tests to assess adolescent footballers. However, these measures are not be sensitive enough to detect true changes in performance in relation to variations in training and match load. Alternative methods must be established that quantify the physiological responses to load experienced by adolescent footballers.

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Contents

List of Figures

List of Tables

Contributions to the Field

Vald Performance Seminar Series Presentation – *Quantifying the Reliability of Physical Performance Tests in Adolescent Footballers* – Oriam Performance Centre (29th June 2019).

Chapter 1 – Introduction

The popularity of football amongst adolescents throughout the world has led to an increase in interest around monitoring the load these players are exposed to (Malone et al., 2014). Each adolescent player will have an individual physiological response in response to the load placed on them (Jeong, Reilly, Morton, Bae & Drust, 2011). Previous research has attempted to establish the effects of load on adolescent players lower body power, through the use of countermovement jump (CMJ) tests. Results of these studies have reported that, despite significant fluctuations in load, tests of CMJ height were not able to detect a real change in power (Malone et al., 2015; Thorpe et al., 2015 & Fitzpatrick, Akenhead, Russell, Hicks & Hayes, 2019). This suggests that CMJ tests may not be appropriate for monitoring responses to load in adolescent footballers. Linear sprint tests are a common method of assessing the speed of footballers (Twist & Highton, 2013) and during a football match, is most common action that precedes a goal (McCunn, Weston, Hill, Johnston & Gibson, 2017). This highlights the importance of speed to adolescent footballers and therefore a reliable method of assessing speed must be quantified. Lower body strength is another important physical quality for adolescent footballers as it aids them to maintain balance and protect the ball under pressure from an opponent (Stolen, Chamari, Castagna & Wisloff, 2005). Despite this, there is a lack of research that analyses the effects of different loads on adolescent footballers' lower body strength. Establishing reliable methods of monitoring power, speed and lower body strength would enable coaches and practitioners to understand the impact of their training (Djaoui, Haddad, Chamari & Dellal, 2017).

Football governing bodies are implementing different strategies in order to optimise the talent development process of many adolescent footballers (Miller, Cronin & Baker, 2015). The Premier League's, Elite Player Performance Plan (EPPP), developed in 2011, is a "long-term strategy with the aim of developing more and better home-grown players," (The Premier League, 2011). The Scottish Football Association (SFA) has since developed their own strategy, known as Project Brave, to increase the effectiveness of elite football academies across the country (SFA, 2018). As adolescent players within a pro-youth academy are exposed to higher training frequencies and volumes, compared to non-academy players (King, 2017), it is important that load is quantified to ensure each player is provided with an appropriate stimulus. The combination of volume and intensity in training and matches is commonly referred to as 'load' (Malone et al., 2015) which determines the physiological responses players exhibit (Jeong, Reilly, Morton, Bae & Drust, 2011). External load is the culmination of physical actions performed by players during training and/or match play (Malone et al., 2015). Internal load is the physiological and perceived exertion players experience during a training session (Malone et al., 2015). Many different metrics are available to measure external and internal load. The use of global positioning systems (GPS) to assess locomotor activities, such as total distance covered and high speed running distance, is common practice in football (Buchheit, Manouvrier, Cassirame & Morin, 2015). The reliability of GPS has been found to be poorer when used over short distances (<10 metres) and high speeds (>14 km/h^{-1}) (Johnston et al., 2012). However, GPS units can be worn under a players' kit, using a custom built vest, during training sessions and matches making it a simple and effective method of collecting external load data (Aughey, 2011 & Buchheit, Gray & Morin, 2015).

Heart rate analysis is regularly used to quantify internal load in elite athletes. Banister et al., (1980) developed training impulse (TRIMP) in order to combine a number of heart rate responses elicited by training, into a single unit of physical effort (Akubat & Abt, 2011). Derivations of Banisters TRIMP have been developed that measure the time spent in different heart rate zones to quantify internal load (Edwards, 1993; Foster, 1995; Lucia, 2003). Measuring time spent above 90% heart rate maximum is another metric used to establish internal load. Maximal oxygen uptake is most effectively trained when players work at an intensity greater than 90% of their maximum heart rate. Measuring the time players spend in this heart rate zone will provide practitioners with information on the most appropriate training methods to improve players maximal oxygen uptake (Helgerud, Engen, Wisloff & Hoff, 2001). Collecting an athletes' rate of perceived exertion (RPE) after each training session is another method of quantifying internal load. Using the Borg category ratio scale, athletes rank their perceived level of exertion from 0 – 10, with 0 being 'rest' and 10 being 'maximal' (Foster et al., 2001). The number given by the athlete is multiplied by the session duration to gain a session RPE score (Foster et al., 2001). Differential ratings of perceived exertion (dRPE) have the potential to provide information on an athlete's central and peripheral exertion (McLaren, Smith, Spears & Weston, 2017). Scores of breathlessness (RPE-B), leg muscle exertion (RPE-L) and technical/cognitive exertion (RPE-T) have previously been assessed in footballers to quantify internal load (Barrett, McLaren, Spears, Ward & Weston, 2018).

RPE methods have been shown to significantly ($p < 0.01$) correlate with heart rate TRIMP methods ($r = 0.50 – 0.85$) in adolescent footballers (Impellizzeri, Rampinini, Coutts, Sassi & Marcora, 2004). Using RPE is also a simple, cost effective method of quantifying internal load (Impellizzeri, Rampinini, Coutts, Sassi & Marcora, 2004). As well as monitoring load, it is important that the physiological responses to load are also assessed.

Each individual player will have different physiological responses to the load imposed on them (Jeong, Reilly, Morton, Bae & Drust, 2011). Therefore, many applied practitioners working with adolescent footballers use different tests to monitor changes in performance associated with daily load (Taylor, Chapman, Cronin, Newton & Gill, 2012). A common method of quantifying speed is assessing linear sprint performance (Twist & Highton, 2013). Rampinini et al., (2011) found that the sprint performance of adolescent footballers takes 48-hours post match to fully recover. This is in contrast to research by Rowsell et al., (2009) who reported that adolescent footballers speed was unaffected, after playing four stimulated matches in four days. Further research is required to assess the effects of training and match load on adolescent footballer's speed. The research reported used a single match to analysis the effects of adolescent players sprint performance. The effects of longer training periods must be analysed to give practitioners a better understanding on the fluctuations in sprint performance during the in-season. Apparatus has recently been developed by Vald Performance (Queensland, Australia) that assesses local muscular strength. The Nordbord is able to test the strength of an athletes' hamstrings and the Groinbar can be used to assess adductor and abductor strength. Information on peak force produced by the muscles is relayed to practitioners in real time. However, there has been no research into the potential use of the Nordbord or Groinbar, as tools for monitoring the response to imposed load.

Before a physical performance test can be credibly used as a physiological monitoring tool, its reliability and sensitivity must be quantified (Thorpe et al., 2015).

Relative reliability offers information on the reproducibly of a test at either group or individual level whereas absolute reliability provides information about the between day reliability of a test (Scott, McLaren, Caia & Kelly, 2018; McMahon, Lake & Comfort, 2018). The sensitivity of a test refers to its ability to detect a true change in performance, outside the noise of the assessment (Thorpe et al., 2015). The reliability of linear sprint tests is well established in adult populations (Hetzler et al., 2008) but to date there is limited research into its reliability in adolescents. Similarly, the reliability of the Nordbord and Groinbar has previously been quantified in adults (Opar, Piatkowski, Williams & Shield, 2013; Ryan, Kempton, Pacecca & Coutts, 2018) but not in an adolescent cohort.

Using reliable tests to monitor adolescent footballers' physiological responses to load will facilitate effective decisions that balance training and recovery (Thorpe, Atkinson, Drust & Gregson, 2017). Adolescent players must be exposed to some overload training in order to improve performance (Smith, 2003). However, it is essential that enough recovery time is afforded between sessions to allow for physiological adaptation whilst preventing the accumulation of fatigue which may have detrimental effects on performance (Meeusen et al., 2013). As adolescent players are still growing, they are at higher injury risk than adult players (Naughton, Farpour-Lambert, Carlson, Bradney & Van Praagh, 2000). Higher injury incidence has been found for acute injuries in adolescent players 6 months pre and post peak height velocity (PHV) (Bult, Barendrecht and Tak, 2018). Furthermore, more overuse injuries have been reported in players who are 1 year pre-PHV compared to 1 year post-PHV (van der Sluis, Elferink-Gemser, Brink and Visscher, 2015). This highlights the importance of monitoring the load-response relationship in this population. The maturation status of an adolescent player can also have an effect on physical performance measures, such as linear speed (McCunn, Weston, Hill, Johnston & Gibson, 2017). Therefore, practionoers must be confident testing protocols are reliable within the adolescent population so that informed decisions can be made on these players development.

The aims of this thesis are two-fold: 1) quantify the reliability of a number of physical performance tests in a group of adolescent footballers and 2) using the same physical performance tests, quantify the physiological responses to load in adolescent footballers. Changes in physiological responses will be compared over acute and chronic training periods.

Chapter 2 – Literature Review

Introduction

Across the world, there are more than 22 million adolescents playing football regularly (FIFA, 2007). With such a high participation rate, it is not surprising that many football governing bodies are implementing strategies to aid the development of adolescent footballers (Miller, Cronin & Baker, 2015). The English Premier League introduced the EPPP in 2011 with broad aim of increasing the number of talented players available for selection at an international level (Towlson, 2016). EPPP ambition is to enable English football to provide a world class academy programme that increases the efficacy of youth development (The Premier League, 2011). Other comparable initiatives have been developed in other parts of the UK and also internationally. The SFA have implemented their own strategy to improve talent development within elite football academies. Project Brave aims to "ensure a more efficient pathway to first-team football" by increasing the "focus on talent development and optimise playing opportunities" for young Scottish footballers (SFA, 2018). Adolescent players within these elite academies are usually selected based on a successful initial trial period. Academy players tend to gain access to a higher quantity and quality of coaching and training facilities compared to non-academy players (Miller, Cronin & Baker, 2015). Adolescent players who have more time to develop their technical, tactical and physical qualities have a higher chance of becoming senior professionals (Reilly & Korkusuz, 2011). Therefore, it is important that the load experienced by adolescent players, who attend an elite academy, is quantified in order to ensure an appropriate stimulus is prescribed (Malone, 2014).

Furthermore, monitoring the physiological responses that adolescent players have to different loads will aid practitioners in the design of training regimes that allow players to maximise training time in order to improve different qualities essential to becoming a senior professional (Thorpe, Atkinson, Drust & Gregson, 2017).

Quantifying load in adolescent footballers can be done by a variety of methods that quantify external and internal metrics (Coutts & Cormack, 2014). External load can be measured using global positioning systems (GPS) that provide information on the different locomotor activities of players, depending on their position within a team (Cummins, Orr, O'Connor & West, 2013). Internal load is different for each player (Brink, Nederhof, Visscher, Schmikli & Lemmink, 2010). One method of quantifying internal load is rate of perceived exertion (RPE) which allows each player to score the intensity of training sessions based on their perception of exertion linked to anchor statements (Impellizzeri, Rampinini, Coutts, Sassi & Marcora, 2004). Physiological measures of quantifying internal, such as heart rate and haematological methods, have been found to correlate well with RPE during football specific training (Coutts, Rampinini, Marcora, Castagna & Impellizzeri, 2009). This suggests RPE is a valid indictor of the internal load placed on footballers during a training session. Like RPE, daily wellness questionnaires can be used to monitor the perceptual responses that adolescent footballers have to training and have been found to be a reliable method of doing so (Noon, James, Clarke, Akubat & Thake, 2015).

Tests of linear sprint performance is also a common method used to analyse physiological responses to load (Gathercole, Sporer, Stellingwerff & Sleivert, 2015). Linear sprint tests have been found to have acceptable levels of reliability in adolescent athletes (Darrall-Jones et al., 2016; Morris et al., 2018). However, it's ability usefulness to detect real changes in performance is unknown. New apparatuses have recently been developed (Vald Performance, Queensland, Australia) to assess muscular strength in the hamstring and adductor muscles but once again their reliability and usefulness to detect real change when used in adolescent footballers is unknown. The reliability and usefulness of these methods must be established before their use as monitoring tools can be deemed credible. Therefore, one of the main objectives of this study will be to investigate the reliability and usefulness of linear sprint and muscular strength performance tests in adolescent footballers.

Monitoring load and physiological responses is an essential part of the training process for adolescent footballers. Loads, too high or too low may result in high levels of accumulated fatigue and detraining respectively, whereas suitable loads underpin improvements in physical performance (Buchheit, 2014). The high volume of training placed on adolescent footballers puts them at greater risk of micro traumatic injuries than adults, especially during intense periods of growth (Naughton, Farpour-Lambert, Carlson, Bradney & Van Praagh, 2000). Therefore, monitoring the load of adolescent players is paramount during maturation. Monitoring load also aids the talent development process to ensure that all adolescent footballers are given the opportunity to reach their potential by adjusting individual load within and between micro cycles (Ford et al., 2020; Buchheit, 2014). An aim of the present thesis will be to quantify the load and physiological responses to load in a cohort of adolescent footballers within an elite football academy.

The literature review will discuss the following areas associated with monitoring responses to load: the physical demands of adolescent football; strategies of developing adolescent players; procedures of quantifying external and internal load and their reliability. Methods of monitoring individual responses to load and their ability to detect a true change in performance; the importance of monitoring training and individual responses in adolescent football will also be discussed.

Developing Adolescent Football Players

Football is thought to be the most popular sport in the world, being played in every country around the globe (Reilly & Williams, 2003). In 2007, the Fédération Internationale de Football Association (FIFA) estimated that there had been an increase of 7% in adolescent players (under 18) participating in football representing 22 million registered adolescent players globally. The increase in adolescents participating in football had led to an increased interest in the physical demands of a match. The physical demands of an adolescent football match appear to be dependent on the players chronological age. Harley et al., (2010) used an individualised approach to calculate the match demands of adolescent footballers within a variety of age groups. Peak velocity for each player was calculated using a 20-metre sprint with a 10-metre flying sprint time recorded. These individual peak velocities were used to calculate mean peak velocity for each age group. Finally, the mean peak velocity of each age group was divided by the mean peak velocity of a group of adult footballers and then multiplied by commonly used thresholds to establish age specific speed zones. Results showed that the total distance covered in a match was significantly higher ($p > 0.05$) when comparing an under-16 match (7672 ± 2578 metres) to under-12 (5967 ± 1277 metres), under-13 (5813 ± 1160 metres) and under-14 matches (5715 ± 2060 metres). On average, high-intensity distance, very high-intensity distance and sprint distance accounted for 30.4%, 11.9% and 3.6% of total distance covered respectively, across the under-16, under-15, under-14, under-13 and under-12 age groups. High-intensity distance, very high-intensity distance and sprint distance accounted for 9.2%, 3.1% and 1% of match exposure respectively, across all adolescent age groups (Harley et al., 2010). However, when compared to relative match exposure, in metres/min^{-1}, no significant differences in match work rate were found (Harley et al., 2010). This highlights the importance of analysing both absolute and relative match load when comparing match running performance across different adolescent age groups.

To be successful in football, adolescent players need to improve in a range of technical and tactical skills such as; passing, shooting, dribbling and tackling (Meylan, Cronin, Oliver & Hughes, 2010). Increasing physical capabilities is also necessary for adolescent players in order to cope with the physical demands of the sport. Improving physical qualities will also lead to enhancements in overall performance (Arnason et al., 2004). Physical qualities that are important to adolescent footballers include but are not limited to; speed, agility, lower limb power, strength, flexibility and aerobic endurance (Gil, Gil, Ruiz, Irazusta & Irazusta, 2007). As well as improving technical, tactical and physical abilities, it is important that adolescent footballers are available to train and play throughout the competitive season (Watson, Brickson, Brooks & Dunn, 2016). It is thought the more time adolescent players spend training and practicing their skills, the more chance they will have of becoming a senior professional player (Le Gall, Carling & Reilly, 2006).

Developing adolescent players into senior professionals appears to be a process many football associations and governing bodies are looking to implement in a more effective manner (Miller, Cronin & Baker, 2015). For example, the Scottish Football Association (SFA) have implemented a strategy, known as Project Brave, to improve the “efficiency” of elite adolescent academies. The main objectives of Project Brave are to “bring a greater focus to talent development and optimise playing opportunities,” as well as “ensuring a more efficient pathway to first-team football,” (SFA, 2018). However, it is this authors’ belief that Project Brave aims to increase effectiveness of elite adolescent academies as opposed to efficiency. Increasing the number of adolescent footballers who progress from elite adolescent football to elite senior football should be the priority for all football governing bodies, irrespective of the different strategies put in place to achieve this.

Many professional football club’s identity adolescent players who they believe have the potential of becoming a senior professional. These adolescent players are invited to join the clubs’ academy where they have the opportunity to train and develop in an elite environment. Adolescent footballers who are part of an academy are exposed to higher training volumes than non-academy players (King, 2017). Therefore, it is of paramount importance that load is regularly monitored. Training and match load data can be used by coaches and practitioners to aid the periodisation process. Day to day alterations in load can be made to ensure each adolescent player is being exposed to an appropriate training stimulus that allows for physiological adaption whilst ensuring the accumulation of fatigue rarely occurs (Buchheit, Manouvrier, Cassirame & Morin, 2015).

Methods of Monitoring Load

Quantifying individual load and subsequent physiological and perceptual responses for every training session and match can be challenging in team sports, such as football. The combination of duration and intensity is referred to as load (Malone et al., 2015). The culmination of physical actions performed by players during a training session or match play is referred to as external load and is measured in duration and distance covered in various running modalities. The physiological and perceived stress placed on the athlete during a training session is known as the internal load. Each athlete will have different levels of internal load imposed on them during training and competition (Brink, Nederhof, Visscher, Schmikli & Lemmink, 2010). For athletes involved in team sports, a combination of both external and internal load monitoring, is suggested due to the high-intensity intermittent nature of training and matches. Research has shown that in the same training session, external load showed the greatest inter player variation during a technical and tactical training drills due to position specific demands whereas during containing more high speed running, accelerations and decelerations internal load showed more variation (Weaving, Marshall, Earle, Nevill & Abt, 2014). Therefore, the use of both external and internal load monitoring is recommended.

External Load Monitoring

Advances in microtechnology has enabled applied sport scientists to monitor athletes in real time. Devices such as Global Positioning Systems (GPS) and accelerometers give detailed information on the external load being placed on an athlete during training and matches (Coutts & Cormack, 2014). GPS units can measure the speed and movement patterns of an athlete. This data will not only enable external load to be quantified but also provide information on position specific, physiological workload for a variety of team sports (Cummins, Orr, O'Connor & West, 2013). Modern GPS units are small, lightweight and able to store up to 4-hours of data. GPS units are placed into the back of a purpose-built GPS vest that can be worn under an athletes' kit. (Buchheit, Gray & Morin, 2015). This makes them practical and suitable for use in field sports (Aughey, 2011).

Currently, there are GPS units that collect data at a number of different frequencies. Literature suggests that the higher the frequency of the GPS unit, the more reliable and valid the measure (Jennings, Cormack, Coutts, Boyd & Aughey, 2010; Varley, Fairweather & Aughey, 2012). GPS units have also been found to have improved reliability when used over longer distances and at slower speeds. Coefficient of variation (CV) was decreased from 32.4% to 9.0% when used for sprint distances of 10-metres and 40-meters respectively, when using a 5-Hz GPS unit. The CV was reduced further to 3.8% when the same GPS unit was used during participation in a 140-metre modified team sport running circuit (Johnston et al., 2012). As sprints completed by footballers during a match rarely exceed 20-metres in distance and 4 seconds in duration (Carling, Bloomfield, Nelsen & Reilly, 2008), the reliability of GPS units to quantify high-intensity actions in footballers is questionable.

The validity and reliability of GPS units at different velocities has also been a popular area of research. GPS error has been found to be lower at slower speeds with one study finding that standard error of estimate (SEE) was 0.7% at a walking speeds of 1.7 m/s^{-1} compared to a SEE of 5.6% at a running speed of 6.0 m/s^{-1} (Portas, Rush, Barnes, & Batterham, 2007). Johnston et al., (2012) supports these findings as their research found that at low intensity activity (<13.99 km/h^{-1}) typical error of measurement (TEM) was 4.9%. During high-intensity running (14.00 – 19.99 km/h^{-1}) TEM increased to 7.9%. Finally, during very high-intensity running (>20.00 km/h^{-1}) TEM increased again to 12.7%. The study concluded that applied sport scientists should be cautious when using GPS units to analyse workloads above 20 km/h^{-1} (Johnston et al., 2012).

Until recently, GPS units on their own are unable to quantify the forces imposed on an athlete such as, impacts from player-to-player collision and contacts with the ground, such as falls and foot strikes (Carling, Bloomfield, Nelsen & Reilly, 2008). However, modern GPS units with built in triaxial accelerometers allow practitioners to measure the body load imposed on an athlete. The accelerometer measures the acceleration of an athlete in the X, Y and Z axis and expresses the body load in G-force (Cummins, Orr, O'Connor & West, 2013). Further improvements to technology has allowed the combination of triaxial accelerometers and GPS data to be quantified and is termed PlayerLoad. PlayerLoad ™ data provides a cumulative measure of rate of change in accelerations in anteroposterior, mediolateral and vertical axial planes and has shown moderate to high test-retest reliability (ICC = 0.80 – 0.99) and absolute reliability (%CV = 3.1 – 8.7) when used during a football match (Barrett et al., 2016; Barreira et al., 2016). The use of GPS with imbedded triaxial accelerometers, like PlayerLoad ™, is common practice in elite team sport and may provide a more complete picture of the locomotor demands of an athlete (Buchheit, Gray & Morin, 2015; Waldron, Twist, Highton, Worsfold & Daniels, 2011).

GPS units and accelerometers are widely used by many football teams to quantify external load. GPS units are practical, portable and provide data on the speed and movement of team athletes during training and matches. However, their accuracy is dependent on the frequency at which the GPS unit collects data. The literature has found measurements to have reduced validity and reliability when used at high speeds and short distances. This may be of concern to applied sport scientists who work with football players due to the amount of distance covered at high speed during training and matches (Carling, Bloomfield, Nelsen & Reilly, 2008; Lambert & Borresen, 2010; Harley et al., 2010). GPS units are also expensive and purchasing enough to cover the needs of a whole squad may not be cost-effective even for some elite teams (Carling, Bloomfield, Nelsen & Reilly, 2008).

Internal Load Monitoring

To monitor internal load in team sports, the duration and intensity of each training session and match must be quantified (Impellizzeri, Rampinini & Marcora, 2005). While the duration of a training session or match can be measured with ease, measuring the intensity can be more challenging (Alexiou & Coutts, 2008). However, training and match intensity can be quantified objectively by monitoring the heart rate and subjectively using rates of perceived exertion (RPE). These are the two most common methods of monitoring internal load in team sport athletes (Little & Williams, 2007).

Heart Rate

Measuring an athletes' heart rate to describe and determine internal load is based on the linear relationship between an individuals' oxygen uptake (VO_2) and heart rate over a wide range of steady state submaximal workloads (Åstrand, Rodahl, Dahl & Stromme, 2003). However, caution should be exercised when using heart rate to measure internal load in high-intensity, intermittent team sports. Training impulse (TRIMP) (Banister et al., 1980) is a method which has been developed in order to combine all perturbations of heart rate caused by training into a unit 'dose' of physical effort (Akubat & Abt, 2011). Banister et al., (1980) were the first to impose the use of TRIMP. They stated that measuring an individuals' heart rate response to exercise may be an effective way to quantify the internal load placed on that individual. TRIMP is calculated by using; the duration of a training session or match, the athletes resting heart, the athletes maximum heart rate and the athletes mean heart rate (Borresen & Lambert, 2009). However, using mean heart rate to quantify TRIMP will not reflect the true internal load placed on athletes who are involved in intermittent, team sports as it fails to account for short, but important, periods of high-intensity exercise and the delayed response of the sympathetic branch after sudden increases in exercise intensity (Stagno, Thatcher & van Someren, 2007). Therefore, derivations of Banisters' original TRIMP model have been developed. Foster et al., (1995) proposed that an exercise score could be calculated by assigning each heart zone a number and multiplying the duration spent in each heart zone by its allocated number. Heart rate zones are numbered as follows: 50%-60% = 1; 60%-70% = 2; 70%-80% = 3; 80%-90% = 4; 90%-100% = 5 (Esteve-Lanao, Foster, Seiler & Lucia, 2007). Another method is to use heart rate zones that represent low- intensity exercise (values below ventilatory threshold (VT) or below 70% VO_2 max); moderate-intensity exercise (values between VT and respiratory compensation point (RCP) or between 70%-90% VO_2 max) and high-intensity exercise (values above RCP or above 90% VO_2 max) (Lucia, Hoyos, Santalla, Earnest & Chicharro, 2003). However, a limitation of these methods is that the weighting factor of each zone increases linearly, although anaerobic and lactate threshold vary between individuals. Therefore, the metabolic stress experienced by individuals, such as when lactic acid can no longer be removed from the muscles at the same rate it is being produced, might be different although their heart rate may be within the same zone (Borresen & Lambert, 2009).

There are a few limitations of using heart rate methods to quantify internal load. Each method requires a significant amount of time and work to determine and monitor on a daily basis, especially in a team sport setting. Although obtaining heart rate information from a heart rate monitor is simple, downloading and analysing the data requires a high level of technical proficiency and expertise. Potential equipment failure, leading to the loss of heart rate data of athletes is a further disadvantage (Coutts & Cormack, 2014). The short, intense bursts that occur during football, could lead to a players' heart rate being unreflective of the intensity of the training session or match (Achten & Jeukendrup, 2003; Aroso et al., 2004).

Rate of Perceived Exertion

An alternative method for quantifying internal load is to record an athletes' rating of perceived exertion (RPE). Borg (1982) described perceived exertion of exercise as a combination of information from the peripheral muscles and joints that are doing the work, the central cardiovascular and respiratory systems and the central nervous system. A number of different scales exist. The 15-point scale was first constructed by Borg and designed so that perceptual ratings on the scale increased in a linear relationship with heart rate and oxygen consumption, during exercise. The scale starts with the number 6 and increases up to number 20. An estimate of heart beats per minute^{-1} (bpm^{-1}) can be calculated by simply adding a 0 on the end of the number on the scale given by an individual. For example, if an athlete gave a score of 14, it can be estimated that the athletes heart rate is 140 bpm^{-1}. However, the literature states that this is only the case during steady-state exercise (Borg & Kaijser, 2006). Little and Williams (2007) conducted a study into the reliability of Borgs' 15-point RPE scale, using senior footballers. Each player (n = 28, 24 ± 5 years) verbally communicated their RPE score after the completion of a high-intensity, football specific, small-sided game. Players also had their heart rate monitored during the small-sided games that ranged from 2v2 to 8v8 players per team. CV of the RPE scores ranged between 5.1% and 9.9% for each of the small-sided games. This would suggest the 15-point RPE scale is a reliable measure of exercise intensity in senior footballers. However, the relationship between RPE score and heart rate measures was found to be not significant ($p = 0.20$). The researchers suggest this may be due to the relationship between heart rate and energy expenditure becoming non-linear during very high-intensity exercise. However, the researchers do concede that some individuals may perceive the same training intensity differently due to their psychological state. Therefore, the use of both RPE and heart rate methods of internal load monitoring may be optimal.

Since not all physical responses have a linear relationship with exertion, especially during high intensity exercise, the category-ratio 10 (CR-10) RPE scale was developed. This scale uses values ranging from 0 to 10 and each value is anchored by a verbal expression, each defining intensity as harder than the previous expression (e.g. strong and very strong). A high correlation between the category-ratio RPE scale and both muscle and blood lactate has been described in the literature (Borg, Noble, Jacobs, Ceci & Kaiser, 1983). The category-ratio RPE scale is thought to be of best use in high-intensity sports, such as football, due to the fluctuation in exercise intensity throughout a training session or match (Coutts & Cormack, 2014).

RPE scores have been used in order to quantify the intensity of training sessions and matches in football. The session-RPE (s-RPE) is calculated by multiplying the duration of a training session or match by the corresponding RPE given by the athlete upon its completion (Wrigley, Drust, Stratton, Scott & Gregson, 2012). It appears that s-RPE has positive relationships with other methods of quantifying load. Gaudino et al., (2015) analysed the relationship between s-RPE scores and external load in football players. A group of 22 senior footballers (26 ± 6 years) had their s-RPE scores and external load, using a 10-Hz GPS unit integrated with a 100-Hz accelerometer, collected throughout a competitive season. Significant correlations ($p < 0.001$) were found when comparing total high speed running distance ($r = 0.61$), number of accelerations ($r = 0.63$) and number of impacts ($r = 0.73$) to s-RPE score throughout the course of the season. Results of this study suggest that s-RPE may be a good judge of external load placed on adult footballers throughout a season. However, the same theory may not apply to adolescent footballers who experience different physiological demands, in terms of distance covered and number of accelerations (Rebelo, Brito, Seabra, Oliveira & Krustrup, 2014). In a group of adolescent footballers ($n = 19$, 17.6 ± 0.7 years) s-RPE scores and heart rate measurements were collected over a 7 week in-season period. Heart rated based TRIMP was calculated using suggested methods from Edwards, Banister, and Lucia, that have been previously described in this literature review. All individual s-RPE scores significantly ($p < 0.01$) correlated with Edwards ($r = 0.54 – 0.78$), Banisters' ($r = 0.50 – 0.77$) and Lucia's ($r = 0.61 – 0.85$) heart rate based methods. (Impellizzeri, Rampinini, Coutts, Sassi & Marcora, 2004). The results of this study suggest s-RPE may be a more cost and time effective method of monitoring load in adolescent football players. Recent research into the perceptual and physiological responses to different high intensity running drills in adolescent footballers has been published. A number of methods, including RPE using the CR-10 scale, were used to collect the internal load of 17 adolescent footballers (14.9 ± 0.6 years) after; a high intensity running (HIR) drill, a repeated sprints (RS) drill and a drill that combined both HIR and RS. Results found RPE scores to be highest during the RS drill (6.3 ± 1.4) and lowest during the HIR drill (5.9 ± 1.7). Similarly modified TRIMP scores were found to be highest during the RS drill (48.6 ± 12.7) and lowest during the HIR drill (43.2 ± 16.2) (Gibson, Henning & Twist, 2018). These results suggest that adolescent footballers may be able to use RPE to estimate the physiological stress placed on them during high-intensity drills. Previously it had been suggested that adolescent players RPE scores should be collected 10 minutes after completing training to encourage the younger players to think about the intensity of their training session in its entirety and not just the last drill of that session (Foster, 1998). However, more recently no differences were found in the RPE scores of adolescent footballers collected immediately after the completion of training or 30 minutes after (Fanchini, Ghielmetti, Coutts, Schena & Impellizzeri, 2015).

RPE is a simple, time-efficient and cost-effective method that shows good levels of reliability (Impellizzeri, Rampinini, Coutts, Sassi & Marcora, 2004). It also has strong relationships with external and heart rate based methods of monitoring load (Coutts & Cormack, 2014; Gaudino et al., 2015; Scott, Black, Quinn & Coutts, 2013). Therefore, due to its non-invasive nature and strong validity with other methods of quantifying load, RPE appears to be a valid method of collecting data on the internal load of adolescent footballers.

Assessing Individual Responses to Load

It would be unwise to assume that each athlete in a team responds in the same manner to a set load, or indeed experiences a set load. Although this may be challenging in a sporting environment, it is essential that coaches and sport science staff monitor and analyse individual physiological and psychological responses to external and internal loads (Coutts & Cormack, 2014). Adolescent footballers are required to play matches once and on occasion twice per week. Hence, the balance between training adaption and recovery is of importance to coaches and sport science personnel. Monitoring tools in adolescent football are often limited by expense, time constraints and ease of data collection. Therefore, the most common field based monitoring methods, and their ability to detect changes in load, are described in the following section of this literature review.

Wellness Questionnaires

Wellness Questionnaires are commonly used to assess how load is affecting specific components of wellness over time. Changes in an athletes' mood and affective states have been described as an early indication of overtraining (Gastin, Meyer & Robinson, 2013). The Profile of Mood States Questionnaire, the Recovery-Stress Questionnaire for Athletes, Daily Analysis of Life Demands for Athletes and the Total Recovery Scale are able to detect changes in wellness, training related stress, strain and recovery (Moalla et al., 2016). Hooper and Mackinnon (1995) created a psychometric questionnaire that can be used to monitor well-being factors such as sleep duration and quality, muscle soreness, fatigue and stress. Fessi et al., (2016) used the Hooper questionnaire to assess responses of senior footballers (n = 17, 23.7 ± 3.2 years) to different loads. Ratings in stress, sleep, fatigue, muscle soreness and load were collected for all players during the last week of pre-season and during an in-season week. Unsurprisingly, external load was found to be significantly greater ($p < 0.01$, ES > 2) during the pre-season week compared to the in-season week. Results showed that during the pre-season week perceived; quantity of stress (ES = 1.5), fatigue (ES > 2) and muscle soreness (ES > 2) were all significantly higher ($p < 0.01$) when compared to the in-season week. Perceived quality of sleep (ES = 1.2) was found to be significantly lower ($p < 0.01$) during the pre-season period. The outcome of this study shows that lower levels of perceived wellness are present during periods of training where load is high. The use of the Hooper questionnaire appears to be a useful method of monitoring the phycological and psychometric responses to different loads in footballers. Research analysing the relationship between load and perceptions of wellness in adolescent footballers has also been conducted. A group of 14 adolescent footballers (17 ± 1 years) completed a perception of wellness and recovery questionnaire between 1 and 4 times per week during 4 separate training blocks in a season. As the season progressed, training exposure (hours per week) increased significantly ($p < 0.05$) for all players. Consequently, results of the wellness questionnaires found a moderate decrease (ES = 0.30, $p < 0.05$) in the perceived quality of sleep, moderate increases in perceptions of fatigue (ES = 0.36, $p < 0.05$) and stress (ES = 0.47, $p < 0.05$), and a large increase in perceptions of muscle soreness (ES = 0.53, $p < 0.05$) as the season progressed (Noon, James, Clarke, Akubat & Thake, 2015). Results of this study concur with those of Thorpe et al., (2015) who found that day-to-day variability of total high intensity running distance had moderate-to-strong correlations ($r = -0.51$, $p < 0.001$) with perceived levels of fatigue in footballers ($n = 10$, 19.1 ± 0.6 years). These results suggest that perceived ratings of wellness are sensitive to the daily fluctuations of in-season load. Perceived ratings of wellness are a time-effective, simple and non-invasive method of assessing adolescent footballers’ responses to in-season load. Therefore, monitoring perceived wellness ratings appears to be a valid method of quantifying subjective responses to load.

Linear Speed Tests

Sprint tests are a popular method of monitoring speed in the field (Twist & Highton, 2013). Electronic timing gates are normally used to measure sprint times in the field due to their high levels of precision and accuracy. Hetzler et al., (2008) found electronic timing gates to have excellent relative reliability (ICC = 0.98) when measuring multiple sprint split times. When comparing the use of a hand held stop watch for measuring multiple split times, only 2.4% of the results agreed with the electronic timers. The hand held stop watch also had a mean error of 0.16 seconds. Results of this study indicate electronic timing gates are the best method for measuring sprint times in the field. However, electronic timing gates are not without limitation. Inconsistent procedures are found in the literature with varying timing gate heights being reported from hip, knee and head height (Altmann et al., 2017). The height at which the timing gate is set at has been shown to influence the time recorded during a linear sprint test (Cronin and Templeton, 2008). To ensure validity, practitioners should aim to minimise the variation in timing gate height between individuals, even though this may be time-consuming and challenging in a team-sport setting.

Previous research has found that sprint performance is impaired immediately after strenuous exercise. A group of team sport athletes (n = 8, 23.0 ± 3.7 years) had their 20-metre sprint times recorded prior to taking part in a Yo-Yo fatiguing protocol, that was performed to exhaustion. The fatiguing protocol was performed on an outdoor concrete track to elicit a neuromuslcar load similar to team sport activities. Players' sprint times were then re-tested immediately after, 24-hours after and 72-hours after the fatigue protocol and results were compared to the baseline measure taken prior to the fatigue protocol. Sprint performance largely decreased (ES = 3.65) immediately after the fatiguing protocol. However, when re-tested 24-hours later, sprint performance showed no difference to baseline measures and 72-hours later, moderate improvements were (ES = 1.08) found. These results suggest that the sprinting ability of team sport athletes recovers quickly after a fatiguing period of exercise (Gathercole, Sporer, Stellingwerff & Sleivert, 2015). Katis and Kellis (2009) reported that the sprint ability of adolescent footballers (n =34, 13.0 ± 0.9 years) decreased significantly ($p < 0.05$) immediately after a 70-minute training session but no follow up measures were taken in this study. However, Rampinini et al., (2011) measured the 40-metre sprint times of 22 adolescent footballers (19 ± 1 years) prior to a 90-minute match, 40-minutes post match, 24-hours post match and 48-hours post match. Compared to pre-match sprint times, 40-minute post match sprint times significantly increased (slower time) ($p < 0.001$) by 2.6%. Sprint times were closer to pre-match values 24-hours post match but still 0.9% higher ($p = 0.49$). No significant differences ($p > 0.22$) were found when comparing sprint times, prior to match and 48-hours post match. These findings suggest that sprint tests could be used to monitor the recovery of speed following training and match play. Unlike CMJ tests, sprint tests are largely determined by concentric function, which is a possible reason for quicker recovery times in athletes (Gathercole, Sporer, Stellingwerff & Sleivert, 2015). Sprint tests appear to be a good indicator of speed after intense periods of exercise and could be used to assess the physiological responses to daily load. However, the reliability of liner sprint tests when used in adolescent footballers has not been investigated. The reliability of sprint tests and consequently their ability to detect meaningful changes in adolescent footballers, requires further research.

Muscular Strength Tests

Sprinting, quick changes of direction and over reaching for the ball are all actions that take place during a football match and is the suggested cause of hamstring and groin strains in footballers (Ekstrand, Hägglund & Waldén, 2011). Adolescent footballers are at greater risk of these injuries occurring as they grow and mature. It is suggested that monitoring the strength of key muscle groups in adolescent footballers may identify players who are struggling with their current load and are at a greater risk of injury occurrence (Read, Oliver, De Ste Croix, Myer & Lloyd, 2016). Recently, Vald Performance (Queensland, Australia) has developed new apparatuses for assessing hamstring, abductor and adductor strength.

The Nordbord hamstring testing system is able to provide information on the maximum force, peak torque and imbalances between the hamstring muscle group in each leg (Bjorkheim, 2017). The Nordbord is a padded board with two ankle hooks. Players kneel on the padded board and have their ankles secured superior to the lateral malleolus. The two ankle hooks are connected to two force cells that measure the force at which the ankle hooks are being pulled whilst an individual completes a Nordic hamstring curl. The data is transmitted and displayed on a tablet or smart phone in real time (Opar, Piatkowski, Williams & Shield, 2013; Bjorkheim, 2017). The Nordbord requires little skill to operate compared to isokinetic dynamometry and hand held dynamometry which require an individual to be highly skilled to use the proper technique (Stark, Walker, Phillips, Fejer & Beck, 2011). Research has found the Nordbord to have moderate to high test re-test reliability (ICC = 0.83 – 0.90) and an acceptable level of typical error (CV = 5.8% - 8.5%) in adult populations (Opar, Piatkowski, Williams & Shield, 2013). Although some studies have used the Nordbord to assess hamstring strength in adolescent footballers (McGrath, Gibson, Lombard, Harper & McCunn, 2018; Bjorkheim, 2017), to this authors knowledge no studies have tested the reliability of the Nordbord in this population. Furthermore, the ability of the Nordbord to detect small but meaningful changes in muscular strength is yet to be quantified.

Similar to the Nordbord, the Groinbar, also developed by Vald Performance, is able to measure the maximum force and imbalances between an individuals' abductor and adductor muscles. The Groinbar is made up of a bar with four pads, two for adductor measures and two for abductor measures. Pressure applied to the pads is measured by force cells and data is transmitted to a tablet or smart phone. The Groinbar can be used in supine positions and long and short lever measurements can be recorded (O'Brien, Bourne, Heerey, Timmins & Pizzari, 2018). The Groinbar has shown excellent reliability (ICC =0.94, CV = 6.3%) when measuring isometric adductor and abductor strength from short lever positions and is more accurate compared to dynamometry and a sphygmomanometer (Ryan, Kempton, Pacecca & Coutts, 2018). The reliability of the Groinbar when forces are measured from long lever positions is unknown. However, peak torque adductor scores, measured at long lever positions, from the Grionbar have been found to have a moderate to good relationship (0.63 – 0.71) with peak torque adductor scores, also taken from long lever positions, using a hand-held dynamometer (O'Brien, Bourne, Heerey, Timmins & Pizzari, 2018). Furthermore, hand-held dynamometers have been shown to produce more reliable results when adductor strength is measured from a long lever position compared to a short lever position (Krause, Schlagel, Stember, Zoetewey & Hollman, 2007). Although the Groinbar has been used to assess the adductor strength of a cohort of adolescent footballers (Forsdyke, Salter, Weston & Cresswell, 2018), to this authors knowledge, its reliability and ability to detect small but meaningful changes in muscular strength are unknown.

Assessing Reliability and Usefulness of Monitoring Tools

For all physiological and psychological monitoring tools, reliability and ability to detect real change must be quantified before it can be used in an applied setting (Thorpe et al., 2015). This will give practitioners confidence that daily fluctuations in both external and internal load, resulting in potential meaningful changes in lower body power, speed and muscular strength, can be detected by their monitoring system.

To assess the reliability of a physical performance test within a population, intraclass correlation coefficients (ICC) can be calculated. This type of analysis has been used in team sports previously to quantify the relative reliability of heart rate recovery after a submaximal shuttle test (Scott, McLaren, Caia & Kelly, 2018). The following thresholds were used; >0.99, *extremely high*; 0.90-0.99, *very high*; 0.75-0.90, *high*; 0.50-0.75, *moderate*; 0.20-0.50, *low*; and <0.20 *very low* (Hopkins. 2000). These thresholds show that the higher the ICC of a monitoring tool, the better the relative reliability. Absolute reliability provides analysis of between day reliability of a monitoring tool. Recently, McMahon, Lake and Comfort (2018) quantified the absolute reliability of the flight time to contraction time ratio and the reactive strength index of an individual using a CMJ test. Typical error (TE) expressed as a percentage of the coefficient of variation (%CV) are calculated to quantify the absolute reliability of a physical performance test. A %CV of <5%, 5% -

10% and >10% were set as thresholds for defining *excellent*, *good* and *poor* absolute reliability respectively.

Applied sport scientists commonly quantify the usefulness of a physical performance test by comparing the smallest worthwhile change (SWC) to the TE (Roe et al., 2016). This will give a comparison of test signal (SWC) to test noise (TE). SWC is calculated by multiplying the between subject standard deviation by 0.2. This is due to the fact that Cohens' effect size of 0.2 is deemed *small* (Hopkins, 2004). If SWC > TE the usefulness of a test to detect real change is *good*. When SWC = TE, usefulness is *satisfactory* and when SWC < TE usefulness is *marginal*. These thresholds have been used previously to assess the usefulness of a repeated sprint test in adolescent football players (Castagna et al., 2018).

Importance of Monitoring Load & Response in Adolescent Footballers

The balance between load and recovery is an essential part of any training regime with the aim of enhancing athletic performance (Brink, Nederhof, Visscher, Schmikli & Lemmink, 2010). Not all athletes have the same physiological response to the same training dose, nor do they have the same external response to the same training drills. Therefore, in order to maximise the benefits of training, individual loads and responses must be analysed. This will then allow sport scientists and strength and conditioning coaches to use periodisation, in order to manipulate load on an individual basis to allow for optimal improvements to an athletes' aerobic, cardiovascular and muscular systems (Buchheit, 2014; Coutts & Cormack, 2014). In order to improve performance, athletes must be exposed to some overload training that stresses the body to an extent not experienced before (Smith, 2003). Whilst recovering from overload training, athletes return to a state of homeostasis. During this time that the body goes through physiological changes, so that the same training stimulus does not tax the body to the same extent. This process is known as supercompensation (Coutts & Cormack, 2014). Fatigue is a normal part of the training process and is experienced after training and can temporally impair an athletes' physical performance. This impairment can be acute and last only a matter of hours. However, impairments such as muscle injury and soreness that occur after periods of training, consisting of high eccentric loads, can last up to serval days (Thorpe et al., 2015). With adequate recovery, fatigue is not an issue to be concerned with. However, when appropriate recovery between training sessions is not present, athletes are at risk of entering a state of overreaching. Extended durations in this state can lead to a reduction in levels of athletic performance (Meeusen et al., 2013). Decreased performance in submaximal shuttle run tests and poor perceived psychological wellness have been found to be consequences of overreached adolescent footballers (n = 77, 16.5 ± 1.1 years) (Schmikli, Brink, de Vries & Backx, 2010).

Overreached adolescent footballers are also at an increased risk of injury and illness. A systematic review into the incidence of injury in elite adolescent footballers found that 2.0 to 19.4 injuries occurred per 1000 hours of exposure to training and matches (Pfirrmann, Herbst, Ingelfinger, Simon & Tug, 2016). Between 27% and 33% of these injures were defined as overuse injuries. Overuse injuries are caused by repetitive physiological stresses being placed on the body without sufficient time to recover and are one of the most common injuries in adolescent athletes (Brenner, 2007). Research by Brink et al., (2010) monitored the overall stress and recovery of elite adolescent footballers (n = 53, 16.5 ± 1.2 years) over the course of two competitive seasons. Results from the study showed that physical stress was related to the incidence of both injury and illness, with odds ratios (ORs) ranging from 1.01 to 2.59. Levels of psychosocial stress and recovery were related to the occurrence of illness (ORs = 0.56 – 2.27) in footballers that participated in the study. Helsen et al., (2000) stated that success in football is related to the amount of training hours completed each week. Therefore, it is essential that load and physiological responses are monitored to ensure adolescent footballers are fit and available to train all season long.

Many coaches and sport scientists now implement a load monitoring system (Taylor, Chapman, Cronin, Newton & Gill, 2012). Monitoring load can also aid the talent development process, as many football academies aim to give their players the opportunity to reach their full technical and physical potential (Ford et al., 2020). Assessing responses to load also gives coaches and sport scientists an insight into whether adolescent footballers are responding positively or negatively to both the external and internal loads being placed on them (Thorpe, Atkinson, Drust & Gregson, 2017). This information will be the basis for which adaptations are needed for each individual players' load in order to give them the best chance to be successful. However, to date there is no research available which uses 30-metre sprint performance and local muscular strength tests as physiological monitoring tools, over acute and chronic training periods, in adolescent footballers.

Conclusion

In conclusion, with football governing bodies and football academies striving to develop more adolescent footballers into senior professionals, it is important that load and physiological responses are monitored effectively. The most appropriate methods of monitoring load and individual responses to load have been well documented throughout this literature review. However, the reliability and usefulness of some of these methods when used in adolescent footballers is still unknown. Further research into the fluctuations of load and physiological responses is important. This information could be used to alter the training regimes of adolescent footballers in order to improve the pathway from adolescent football to the senior game by maximising training time and opportunities. The current research will aim to determine the reliability of different tools that are used to monitor the physiological responses of adolescent footballers. Furthermore, load and subsequent physiological effects for a cohort of adolescent footballers over acute and chronic training periods, will also be quantified.

Chapter 3 – Reliability and Usefulness of Physical Performance Tests in Adolescent Football Players.

Introduction

The growing number of adolescents participating in football has led to an increase in research regarding the loads associated with adolescent players and the dose-response relationship with assessments of physical capacity (Akubat, Patel, Barrett & Abt, 2012). Monitoring physiological responses to load is an important part of any physical training schedule. In association football, in-season load fluctuates weekly and is periodised to minimise fatigue and maximise player readiness to compete in weekly matches (Malone et al., 2015). Therefore, it is important to establish the reliability of the measures used to monitor responses to daily load so that practitioners can make more effective decisions on training content and intensity (Meeusen et al., 2013).

Linear sprint tests can be used to assess the physiological responses athletes experience in relation to different loads (Twist & Highton, 2013). Previous research has found that the sprint performance of adolescent footballers is impaired after the match and takes up to 48 hours to return to pre match levels (Rampinini et al., 2011). Research by Ascensão et al., (2008) found that 72 hours post-match, the sprint performance of adolescent footballers was still 0.02 seconds slower than baseline measures. However, Haugen and Buchheit (2015) suggest that an increase in 20-metre sprint time does not have a direct impact on performance during a football match if the increase is less than 0.03 seconds. This is based on the distance and time that one player needs to be ahead of an opponent to win the ball (Haugen &

Buchheit, 2015). Electronic timing gates are preferred to hand-held stopwatches when it comes to measuring linear sprint times in the field and have been found to have excellent levels of relative reliability (ICC = 0.98) in adult populations (Hetzler et al., 2008). However, the reliability of sprint tests within a population of elite adolescent footballers, is still unknown.

Accelerations, decelerations and sharp changes of direction are suggested causes of muscular injuries in footballers (Ekstrand, Hägglund & Waldén, 2011). Previous research has shown that it may take up to 72 hours post match for muscular strength to return to optimal levels (Ascensão et al., 2008). Assessing levels of muscular strength is another method of monitoring individual response to load. Isokinetic dynamometers have been found to be reliable instruments and are generally considered the ‘gold standard’ for measuring muscular strength (Stark, Walker, Phillips, Fejer & Beck, 2011). However, they are expensive and non-portable making their use as a daily monitoring tool, in a field setting, impractical (Desmyttere, Gaudet & Begon, 2019). Although hand-held dynamometry test is a reliable, inexpensive and portable alterative for assessing muscular strength in field based settings, it is subject to between-tester bias and some level of skill and experience is required to administer the test (Whiteley et al., 2012; Kemp, Schache, Makdissi, Sims & Crossley, 2013). The Nordbord and Groinbar are two pieces of apparatus that assess the strength of the hamstrings and adductors, respectively. During Nordbord testing, individuals preform a Nordic curl on a padded board with their ankles secured by two hooks connected to force cells. As a player performs a Nordic curl, the force exerted on the hooks is measured (Bjorkheim, 2017). For Groinbar testing, players can have their adductor and abductor strength tested in both short and long lever positions. An adjustable bar, with movable force transducers, has its height altered depending on which type of test is desired (O'Brien, Bourne, Heerey, Timmins & Pizzari, 2018). The reliability of the Nordbord (ICC = 0.83 – 0.90, %CV = 5.8 – 8.5) and Groinbar (ICC = 0.85, %SEM = 8.2) has been found to be of an acceptable level when measuring the peak forces produced by the hamstring and adductors in adult populations respectively (Opar, Piatkowski, Williams & Shield, 2013; Desmyttere, Gaudet & Begon, 2019). However, the reliability of both pieces of apparatus when used by adolescent footballers is unknown.

Intraclass correlation coefficients (ICC) have previously been used in a team sport setting to measure relative reliability (Scott, McLaren, Caia & Kelly, 2018). Absolute reliability can be assessed by calculating the typical error (TE) of a test expressed as a percentage of the coefficient of variation (%CV) (Hopkins, Marshall, Batterham & Hanin, 2009). Defining the usefulness of any physical performance test is also essential if practitioners wish to use the tests to monitor adolescent athletes (Buchheit, Spencer & Ahmaidi, 2010). Test usefulness is analysed by comparing the TE, also known as the noise of a test, to the smallest worthwhile change (SWC) in terms of performance. SWC is calculated by multiplying the between subject standard deviation of a test score by 0.2. This is based on Cohens effect sizes where an effect size of 0.2 is defined as *small* (Hopkins, 2004). Ideally, the SWC of a test is greater than the TE. If so, practitioners can use the tests with confidence that they will be able to detect true change in physical performance (Pyne, 2003).

The objective of this study is to establish the reliability and usefulness of sprint performance, eccentric hamstring strength and isometric adductor strength tests using the My Jump app, Brower Timing Gates, Nordbord and Groinbar respectively, in a population of adolescent footballers. It is hypothesised that at least one outcome metric in all of the physical performance tests will have acceptable levels of relative reliability and absolute reliability.

Methodology

Experimental Approach to the Problem

A repeated measures approach was used to assess the relative reliability, absolute reliability and usefulness of lower body power, muscular strength and speed tests in a group of adolescent footballers. Each player completed an eccentric hamstring strength, isometric adductor strength and liner sprint test using the Nordbord, Groinbar and Brower Timing System respectively. Testing took place on three separate occasions over a period of four days, with no less than 24 hours and no more than 48 hours between trials. All data was collected during a competitive, in-season micro-cycle where the focus of the training sessions was the continued development of technical, tactical and physical capabilities of the players.

Participants

Forty-six adolescent footballers agreed to participate in this study. However, due to injury, illness and international commitments, only thirty-seven adolescent footballers (age: 14.7 ± 0.8 years; stature: 168.7 ± 7.8 cm; mass: 57.7 ± 9.1 kg; maturity offset: 0.8 ± 0.9 years) completed all three trials, of at least one of the physical performance tests. All players attended the same elite youth academy, and each completed three, 90 minute training sessions during the study. The researcher made no alteration to the players weekly training regime. At the start of the season each player, and their parent or legal guardian, within the youth academy gave written consent for their child’s physical performance data to be used for research purposes. The study was granted full ethical approval by the School of Social Sciences at Heriot-Watt University, conforming to the declaration of Helsinki.

Procedures

All testing took place in the early evening prior to the players’ regular squad training. It is recommended that linear sprints should take place at the end of a physical performance testing battery due to the high levels of fatigue produced from sprinting. This ensures that the results of the other performance tests, within the testing battery are not affected (Baechle & Earle, 2008; Turner et al., 2011). Therefore, in the following order, each player completed the Nordbord and Groinbar tests indoors before making their way outside onto a synthetic grass football pitch to complete the liner sprint test. Outdoor temperature and wind conditions were similar between the three trials (temperature: 10 – 13°C; humidity: 86 – 95%; wind: 9.9 – 12.4 mph). Each of the four tests were part of the players normal physical assessment protocol at the club. Therefore, no habituation period with the protocol or equipment was necessary for any of the trials. Identical procedures were carried for each of the three trials. Prior to testing, all players completed a warm-up that included a raise, activate, mobilise and potentiate (RAMP) phase. The RAMP warm-up was used as it was non-fatiguing and optimally prepared the players for the high-intensity nature of the testing battery (Jeffreys, 2017).

Anthropometrics & Maturity Offset

One week prior to testing, each player underwent an anthropometric assessment. Stature and seated heighted were measured to the nearest 0.1 centimetre using a Seca Alpha stadiometer. Body mass was measured to the nearest 0.1 kilogram using calibrated Seca Alpha scales. Age at peak height velocity (PHV) was estimated using the Mirwald predication equation (Mirwald, G. Baxter-Jones, Bailey & Beunen, 2002). Maturity offset was calculated by subtracting the players age at PHV from their chronological age.

Eccentric Hamstring Strength

Each player completed the eccentric hamstring strength test using the Nordbord (Vald Performance, Queensland, Australia). The Nordbord is a padded board with two ankle hooks that are each connected to force cells that record the force being produced by the hamstrings during a Nordic hamstring curl (Bjorkheim, 2017). Each player knelt onto the padded board and had their ankles secured superior to the lateral malleolus by the ankle hooks. The researcher then instructed the player to complete three maximum effort Nordic curls, encouraging them to lower their torso to as close to parallel with the ground as possible. Each player took a 5-10 second rest between each Nordic curl. Data was transmitted in real time into the researchers' smart phone using the Scorebord app (Vald Performance, Queensland, Australia) before being uploaded onto the Dashbord database (Vald Performance, Queensland, Australia). During each Nordic curl, the Nordbord provided data on the peak force and peak torque produced by both the right and left hamstrings of each player. The highest force and torque produced by each player was imported from the

Dashbord database into a Microsoft Excel spreadsheet, after each trial. Figures 1a and 1b, depict the protocol of using the Norbord.

Isometric Adductor Strength

In each trial, after completing the eccentric hamstring strength test, players moved straight onto the isometric adductor strength test, using the Groinbar (Vald Performance, Queensland, Australia). The Groinbar is made up of a metal bar that can be adjusted in height depending on the testing position desired. The bar has four force pads attached to it, each connected to a force cell, that is able to measure the force being applied to it during different groin squeezes (O'Brien, Bourne, Heerey, Timmins & Pizzari, 2018). For long lever testing each player lay in a supine position, with their knees and hips at 0°. The force transducers were positioned perpendicular to the medial malleoli. The researcher then instructed each player to complete an isometric adductor squeeze, with maximum effort, for 5 seconds. Each player completed three long lever efforts with a 5 - 10 second rest separating each effort. The bar was then adjusted in height, so each player could complete three isometric adductor squeezes using short levers. Staying in a supine position, each player flexed their hips to 60° and the force transducers were set perpendicular to the medial femoral. Once again, the researcher asked each player to complete three, maximum effort, isometric adductor squeezes. A 5 -10 second rest was given between each effort. Data for both long and short lever squeezes were transmitted in real time to the researchers' smartphone, through the Scorebord app. Peak force for the right and left adductor muscles was produced at both long and short levers. All data was uploaded to the Dashbord database and the highest force from each adductor, for both long and short lever tests, was imported into a Microsoft Excel spreadsheet for each of the three trials. Figures 2a and 2b depict the protocols of using the Groinbar in long and short lever positions, respectively.

Sprint Performance

On completion of the isometric adductor strength test, players went outside to have their sprint performance assessed. Using a trundle wheel, distances of 5, 10, 20 and 30-metres were measured and marked with a piece of white tape before the placement of a pair of Brower Timing Gates (Brower Timing Systems, Draper, Utah). A pair of gates were set-up at the start of the 30-metre distance, in order to start the electronic timer. As a player cut the light beam at each distance, the electronic timer produced a split interval time. Each player started the sprint test 30 centimetres behind the first pair of timing gates. This procedure has been used in previous reliability studies using Brower Timing Gates (Shalfawi, Enoksen, Tønnessen & Ingebrigtsen, 2012). Two plastic markers were placed 2-metres beyond the last pair of timing gates and each player was encouraged not to begin decelerating until they were past these markers. This ensured the times recorded were a true representation of the players' sprint performance. Furthermore, a league table structure to rank each players' sprint time was used for each trial. The league table was communicated to the players at the end of each trial in order to motivate them to improve on their ranking in the next trial. This procedure was used, as it has been found adolescent athletes who compete in team sports, are prone to having ego-orientated motivates such as being better than their team mates (Rottensteiner, Tolvanen, Laakso & Konttinen, 2015). Each player was allowed one practice run through the gates at around 75% of maximum before the test began. Two maximum effort sprints were completed by each player and times were recorded for 5, 10, 20 and 30-metre distances. The lowest time for each distance, for each trial, was imported into a Microsoft Excel spreadsheet.

Statistical Analysis

All statistical analysis was performed using predesigned Microsoft Excel worksheets (Hopkins, 2015) and SPSS software (Version 25.0, IBM Corp., Armock, NY, USA). Shapiro-Wilk tests of normality were completed and showed all data to be parametric ($p > 0.05$). Confidence limits were set at 95% for all statistical analysis. Relative reliability of each physical performance test variable was calculated using ICC with thresholds set at; >0.99, *extremely high*; 0.90-0.99, *very high*; 0.75-0.90, *high*; 0.50-0.75, *moderate*; 0.20-0.50, *low*; and <0.20 *very low*. (Scott, McLaren, Caia & Kelly, 2018). For each performance variable, absolute reliability was also calculated by determining TE as a %CV according to Hopkins et al., (2009). A CV of < 5%, 5%-10% and >10% were set as thresholds for defining a test as having *excellent, good* or *poor* reliability, respectively (McMahon, Lake & Comfort, 2018). The SWC for each performance variable was calculated by multiplying 0.2 by the mean between-player standard deviation (Póvoas et al., 2015). The usefulness of a physical performance test to detect real change is considered *good* when TE < SWC, *satisfactory* when TE = SWC and *marginal* when TE > SWC (Veugelers, Naughton, Duncan, Burgess & Graham, 2016).

Statistical analysis of Nordbord and Groinbar data was only completed for thirty-six players as one player was late for the first trial and therefore only completed trials two and three. All thirty-seven players completed the three sprint trials and were all included in the statistical analysis of sprint times.

Figure 1a. Start position for Nordic hamstring curl using the Nordbord.

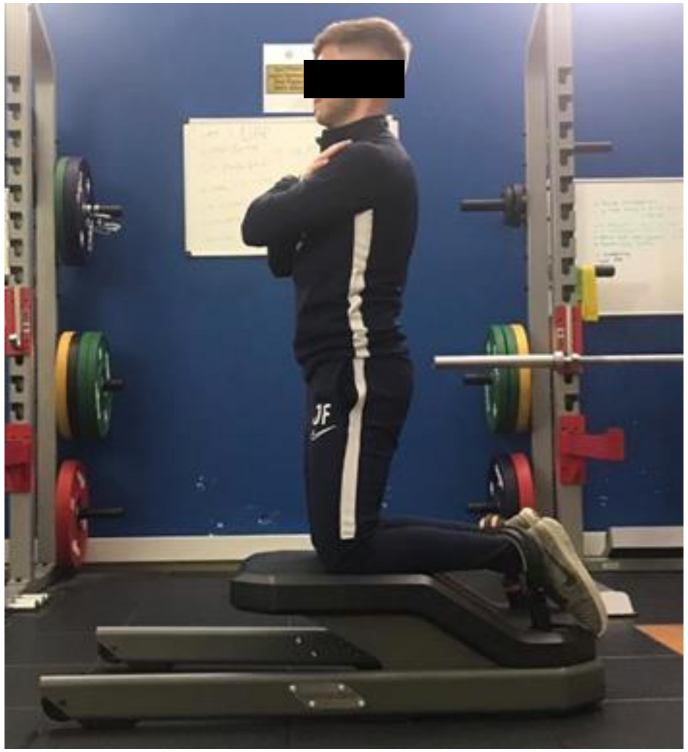


Figure 1b. Mid-point of Nordic hamstring curl using the Nordbord.

Figure 2a. Long lever testing position using the Groinbar.

Figure 2b. Short lever testing position using the Groinbar.

Results

Measures of peak force and peak torque in the eccentric hamstring strength test, displayed *high* ICC and *good* %CV in both the left and right hamstrings. Test usefulness was *marginal* as TE > SWC for all measures. All results for the eccentric hamstring strength test are presented in Table 1a.

Peak force measures of the left and right adductors in the isometric adductor strength test produced *high* ICC at both short and long lever positions. Short lever measures produced *poor* %CV whereas long lever measures produced *good* %CV. As TE > SWC for all test measures in both short and long lever positions, test usefulness was *marginal*. Table 1b displays all results for the isometric adductor strength test.

Increase in distance led to an increase in the ICC produced during the sprint performance test. Both 5-metre and 10-metre sprints displayed *moderate* ICC, 20-metre displayed *high* ICC and 30-metre sprints displayed *very high* ICC. For all distances, *excellent* %CV were produced. The sprint performance test had *marginal* usefulness as TE > SWC for all distances. Results for the sprint performance test are presented in full in Table 1c.

Table 1a. Reliability of eccentric hamstring strength test (n = 36).

	Left Hamstring – Force (N)	Right Hamstring – Force (N)	Left Hamstring – Torque (N.m)	Right Hamstring – Torque (N.m)
Trial 1 (mean ± SD)	271.14 ± 53.45	283.53 ± 54.13	115.25 ± 24.85	120.44 ± 25.15
Trial 2 (mean ± SD)	274.86 ± 54.48	282.53 ± 55.32	115.86 ± 25.42	119.47 ± 25.85
Trial 3 (mean ± SD)	269.92 ± 54.16	279.08 ± 56.90	113.28 ± 24.75	116.69 ± 25.93
Change in mean				
Trial 1 v Trial 2	3.72 (-5.77, 13.21)	-1.00 (-9.64, 7.64)	0.61 (-3.74, 4.96)	-0.97 (-5.18, 3.24)
Trial 2 v Trial 3	-4.94 (-12.53, 2.64)	-3.44 (-11.06, 4.17)	-2.58 (-5.69, 0.53)	-2.78 (-5.87, 0.32)
Trial 1 v Trial 3	1.22 (-10.01, 12.45)	4.44 (-7.22, 16.11)	1.97 (-2.57, 6.52)	3.75 (-1.08, 8.58)
ICC				
Trial 1 v Trial 2	0.87 (0.76, 0.93)	0.90 (0.81, 0.95)	0.88 (0.77, 0.93)	0.89 (0.79, 0.94)
Trial 2 v Trial 3	0.92 (0.85, 0.96)	0.92 (0.86, 0.96)	0.94 (0.88, 0.97)	0.94 (0.89, 0.97)
Trial 1 v Trial 3	0.82 (0.67, 0.90)	0.82 (0.67, 0.90)	0.86 (0.74, 0.93)	0.85 (0.73, 0.92)
Overall	0.87 (0.79, 0.93)	0.88 (0.80, 0.93)	0.89 (0.82, 0.94)	0.89 (0.83, 0.94)
TE				
Trial 1 v Trial 2	19.84 (16.09, 25.88)	18.06 (14.65, 23.55)	9.10 (7.38, 11.86)	8.80 (7.14, 11.48)
Trial 2 v Trial 3	15.84 (12.85, 20.67)	15.91 (12.91, 20.76)	6.50 (5.27, 8.47)	6.47 (5.25, 8.44)
Trial 1 v Trial 3	23.47 (19.03, 30.61)	24.38 (19.77, 31.80)	9.50 (7.70, 12.39)	10.09 (8.18, 13.16)
Overall	19.96 (17.40, 23.72)	19.78 (17.24, 23.50)	8.47 (7.38, 10.06)	8.59 (7.48, 10.20)
CV (%)				
Trial 1 v Trial 2	8.3 (6.7, 11.0)	6.9 (5.5, 9.1)	9.1 (7.3, 12.0)	8.0 (6.4, 10.6)
Trial 2 v Trial 3	6.3 (5.1, 8.2)	5.7 (4.6, 7.6)	6.2 (5.0, 8.1)	5.6 (4.5, 7.4)
Trial 1 v Trial 3	9.3 (7.5, 12.4)	9.0 (7.2, 11.9)	9.1 (7.4, 12.1)	9.0 (7.2, 11.9)
Overall	8.0 (6.4, 10.5)	7.2 (5.8, 9.5)	8.1 (6.6, 10.7)	7.5 (6.0, 10.0)
SWC				
Swc	10.81	11.09	5.00	5.13

ICC = intra-class correlation coefficient; TE = typical error; CV = coefficient of variation; SWC = smallest worthwhile change; N = newton; N.m = newton metre.

Table 1b. Reliability of the isometric adductor strength test (*n* = 36).

	Left Adductor – Short Lever Force (N)	Right Adductor – Short Lever Force (N)	Left Adductor – Long Lever Force (N)	Right Adductor – Long Lever Force (N)
Trial 1 (mean ± SD)	292.78 ± 70.49	308.61 ± 71.49	154.78 ± 29.88	161.44 ± 31.01
Trial 2 (mean ± SD)	306.67 ± 68.84	324.72 ± 64.08	157.11 ± 30.40	162.17 ± 34.45
Trial 3 (mean ± SD)	307.39 ± 69.49	326.97 ± 67.06	156.08 ± 31.36	162.94 ± 32.51
Change in mean				
Trial 1 v Trial 2	13.89 (1.37, 26.40)	16.11 (5.89, 26.34)	2.33 (-4.44, 9.11)	0.72 (-6.05, 7.49)
Trial 2 v Trial 3	0.72 (-15.55, 17.00)	2.25 (-14.35, 18.85)	-1.03 (-5.33, 3.27)	0.78 (-4.16, 5.72)
Trial 1 v Trial 3	-14.61 (-31.04, 1.81)	-18.36 (-35.58, -1.15)	-1.31 (-7.18, 4.57)	-1.50 (-8.47, 5.47)
ICC				
Trial 1 v Trial 2	0.87 (0.75, 0.93)	0.91 (0.82, 0.95)	0.79 (0.62, 0.89)	0.82 (0.68, 0.91)
Trial 2 v Trial 3	0.77 (0.59, 0.87)	0.73 (0.53, 0.85)	0.92 (0.85, 0.96)	0.91 (0.83, 0.95)
Trial 1 v Trial 3	0.77 (0.59, 0.88)	0.74 (0.55, 0.86)	0.85 (0.72, 0.92)	0.80 (0.64, 0.89)
Overall	0.80 (0.69, 0.88)	0.80 (0.69, 0.88)	0.85 (0.76, 0.91)	0.84 (0.75, 0.91)
TE				
Trial 1 v Trial 2	26.16 (21.21, 34.12)	21.37 (17.33, 27.87)	14.16 (11.49, 18.47)	14.15 (11.48, 18.45)
Trial 2 v Trial 3	34.01 (27.59, 44.37)	34.70 (28.14, 45.26)	8.98 (7.28, 11.72)	10.33 (8.38, 13.47)
Trial 1 v Trial 3	34.33 (27.84, 44.78)	35.98 (29.18, 46.93)	12.28 (9.96, 16.02)	14.57 (11.81, 19.00)
Overall	31.73 (27.65, 37.70)	31.38 (27.36, 37.29)	12.00 (10.46, 14.26)	13.15 (11.47, 15.63)
CV (%)				
Trial 1 v Trial 2	9.4 (7.6, 12.5)	8.1 (6.5, 10.6)	9.8 (7.9, 13.0)	9.7 (7.8, 12.8)
Trial 2 v Trial 3	12.5 (10.1, 16.7)	11.8 (9.5, 15.7)	6.5 (5.2, 8.5)	6.6 (5.3, 8.7)
Trial 1 v Trial 3	13.2 (10.6, 17.5)	13.0 (10.4, 17.3)	8.0 (6.4, 10.5)	9.4 (7.6, 12.5)
Overall	11.7 (9.4, 15.6)	11.0 (8.8, 14.5)	8.1 (6.5, 10.7)	8.6 (6.9, 11.3)
SWC				
swc	13.92	13.51	6.11	6.53

ICC = intra-class correlation coefficient; TE = typical error; CV = coefficient of variation; SWC = smallest worthwhile change; N = newton.

Table 1c. Reliability of linear sprint performance test (*n* = 37).

	5-metre (s)	10-metre (s)	20-metre (s)	30-metre (s)
Trial 1 (mean ± SD)	1.16 ± 0.07	1.92 ± 0.09	3.30 ± 0.16	4.60 ± 0.24
Trial 2 (mean ± SD)	1.18 ± 0.08	1.97 ± 0.10	3.35 ± 0.18	4.67 ± 0.25
Trial 3 (mean ± SD)	1.05 ± 0.06	1.84 ± 0.08	3.24 ± 0.15	4.56 ± 0.24
Change in mean				
Trial 1 v Trial 2	0.02 (0, 0.04)	0.05 (0.02, 0.07)	0.06 (0.03, 0.09)	0.07 (0.04, 0.11)
Trial 2 v Trial 3	-0.13 (-0.15, -0.10)	-0.13 (-0.16, -0.11)	-0.11 (-0.14, -0.08)	-0.11 (-0.14, -0.08)
Trial 1 v Trial 3	0.11 (0.09, 0.13)	0.08 (0.06, 0.10)	0.05 (0.03, 0.08)	0.04 (0.02, 0.06)
ICC				
Trial 1 v Trial 2	0.60 (0.35, 0.77)	0.74 (0.55, 0.86)	0.85 (0.72, 0.92)	0.91 (0.84, 0.95)
Trial 2 v Trial 3	0.43 (0.13, 0.66)	0.70 (0.49, 0.83)	0.85 (0.73, 0.92)	0.92 (0.86, 0.96)
Trial 1 v Trial 3	0.59 (0.34, 0.77)	0.78 (0.61, 0.88)	0.92 (0.84, 0.96)	0.97 (0.94, 0.98)
Overall	0.53 (0.35, 0.70)	0.74 (0.60, 0.84)	0.87 (0.79, 0.92)	0.94 (0.89, 0.96)
TE				
Trial 1 v Trial 2	0.05 (0.04, 0.06)	0.05 (0.04, 0.06)	0.07 (0.05, 0.09)	0.07 (0.06, 0.10)
Trial 2 v Trial 3	0.05 (0.04, 0.07)	0.05 (0.04, 0.07)	0.06 (0.05, 0.08)	0.07 (0.06, 0.09)
Trial 1 v Trial 3	0.04 (0.03, 0.05)	0.04 (0.03, 0.05)	0.05 (0.04, 0.06)	0.04 (0.04, 0.06)
Overall	0.05 (0.04, 0.06)	0.05 (0.04, 0.06)	0.06 (0.05, 0.07)	0.06 (0.06, 0.08)
CV (%)				
Trial 1 v Trial 2	4.1 (3.4, 5.4)	2.6 (2.1, 3.4)	2.1 (1.7, 2.7)	1.6 (1.3, 2.1)
Trial 2 v Trial 3	4.9 (4.0, 6.4)	2.7 (2.2, 3.5)	1.9 (1.6, 2.5)	1.5 (1.2, 2.0)
Trial 1 v Trial 3	3.8 (3.1, 5.0)	2.2 (1.8, 2.9)	1.4 (1.1, 1.8)	1.0 (0.8, 1.3)
Overall	4.3 (3.5, 5.6)	2.5 (2.0, 3.3)	1.8 (1.5, 2.3)	1.4 (1.1, 1.8)
SWC				
Swc	0.01	0.02	0.03	0.05

ICC = intra-class correlation coefficient; TE = typical error; CV = coefficient of variation; SWC = smallest worthwhile change; s = seconds.

Discussion

This is the first study to assess the reliability of eccentric hamstring strength, isometric adductor strength and sprint performance tests in adolescent footballers. The findings suggest that all measures of the physical performance tests produced acceptable levels of reliability.

Results show that the eccentric hamstring strength test had *high* levels of relative reliability (ICC = 0.87 – 0.89) and *good* absolute reliability (%CV = 7.2 – 8.1) for measures of peak force and peak torque in both hamstrings. The reliability of measures of peak force did not differ greatly from the reliability of measures of peak torque. This is not surprising, as peak force is used in the calculation of peak torque of a muscle (Decker, 2019). In applied settings, it is suggested both force and torque measures are analysed over the early (100 ms) portion of the force/torque-time curve following force onset (Buckthorpe, 2019). This will provide practitioners with information on the rate of force development (RFD), during an eccentric contraction, of the hamstring muscles. The results of this study agree with the findings of Opar et al., (2013) who assessed the reliability of the Nordbord to test eccentric hamstring strength (ICC = 0.83 – 0.90, %CV = 5.8 – 8.5) in adults. An isokinetic dynamometer, when used to measure eccentric hamstring strength, has been found to have slightly higher levels of relative reliability (ICC = 0.95 – 0.97) compared to the results of this study (Pereira de Carvalho Froufe Andrade, Caserotti, Pereira de Carvalho, André de Azevedo Abade & Jaime da Eira Sampaio, 2013). This was expected as isokinetic dynamometers are considered the gold standard for measuring eccentric and concentric muscular strength. During testing, an isokinetic dynamometer provides a constant velocity, that is set by the tester, throughout a joints full range of motion (Valovich-McLeod, Shultz, Gansneder, Perrin & Drouin, 2004). It is not possible to do this whilst using a Nordbord, potentially leading to slightly lower levels of reliability. The reliability of hand-held dynamometers, when used to measure eccentric hamstring strength, has been found to be slightly lower (ICC = 0.84) than the reliability of the Nordbord used in this study (Thorborg, Bandholm & Hölmich, 2012). Hand-held dynameters are also subject tester skill and experience (Stark, Walker, Phillips, Fejer & Beck, 2011) whereas the Nordbord requires little skill to operate. This further supports the use of the Nordbord as a reliable method to quantify the eccentric hamstring strength of adolescent footballers. To date, there has been no research into the fluctuation of Nordbord scores throughout an in-season period in adolescent footballers.

Results of this study found that short lever measures of isometric adductor strength have *high* levels of levels of relative reliability (ICC = 0.80) and *poor* levels of absolute reliability (%CV = 11.0 – 11.7). This is lower than results of previous reliability studies that used the Groinbar to measure adductor strength in adult footballers (ICC = 0.85, %SEM = 8.2) and in adult Australian rules footballers (ICC = 0.94, %CV = 6.3) (Desmyttere, Gaudet & Begon, 2019; Ryan, Kempton, Pacecca & Coutts, 2018). The lower reliability results of the short lever measures could be explained by the age of the players. It has been suggested the pubic symphysis is not matured fully until the age of 21. This may be the cause for the slightly lower reliability results (Wollin, Pizzari, Spagnolo, Welvaert & Thorborg, 2017). Long lever measures also produced *high* levels of relative reliability (ICC = 0.84 – 0.85). In contrast to short lever measures, long lever measures produced *good* absolute reliability (%CV = 8.1 – 8.6). This is the first study to quantify the reliability of isometric adductor strength from long lever positions, using the Groinbar, as such there is no comparable data in the literature. However, when using a hand-held dynamometer, the isometric adductor strength of senior footballers produced higher levels of reliability (ICC = 0.97. %SEM = 2.5) from long lever positions than the results of this study (Light & Thorborg, 2016). Again, this may be due to the maturation status of the adolescent players. Similar to the results of this study, Light and Thorborg (2016) found long lever measures of isometric adductor strength to have higher levels of reliability than short lever measures. Research by Krause et al., (2007) found that long lever measures produced higher levels of reliability, when testing the unilateral isometric adductor strength of adults, compared to short lever measures. A possible reason for long lever measures producing better levels of absolute reliability is that it is easier to standardise the testing position. During long lever testing, hips are flexed at 0° whereas during short lever testing hips are flexed to 60°. We can be confident that the degree of hip flexion throughout long lever testing remains constant, within and between trials, as players were instructed to lie in a supine position with their legs straight. As such, any flexion of the hips would be more identifiable. Changes in the degree of hip flexion between short lever trials may be the cause for the *poor* levels of absolute reliability found in this study. The results of the study suggest that when using the Groinbar to test isometric adductor strength of adolescent footballers, measures from long lever positions produce reliable results. To date, there has been no research into the changes of Groinbar scores in adolescent footballers, throughout a chronic in-season period. Further research is required before a true assessment of the Groinbars' usefulness can be made.

For the sprint performance test, measures of relative reliability were classed as; *moderate* for both 5-metre (ICC = 0.53) and 10-metre (ICC = 0.74) performance, *high* for 20-metre (ICC = 0.87) performance and *very high* for 30-metre (ICC = 0.94) performance. These results are lower than those of Shalfawi et al., (2012), who also used Brower Timing Gates, and found ICC of 10-metre, 20-metre and 30-metre sprint performance to be 0.91, 0.91 and 0.99 respectively. A possible cause for the lower relative reliability is that the players in the Shalfawi et al., (2012) study were university students who completed no athletic training between trails. This is in contrast to the players in this study who are elite adolescent footballers and trained between trials. Therefore, players in this study were better trained and more accustomed to completing regular sprints than the participants in the Shalfawi et al., (2012) study. Rampinini et al., (2011) reported sprint performance of adolescent footballers can still be impaired 24 hours post match, due to the high levels of fatigue experienced by players. Although relative reliability was still *moderate* to *very high* it is possible that fatigue accumulated during the in-season micro cycle effected the results, leading to slightly lower values compared to the players in Shalfawi et al., (2012) study. Levels of absolute reliability were deemed *excellent* for 5-metre (%CV = 4.3), 10-metre (%CV = 2.5), 20-metre (%CV = 1.8) and 30-metre (%CV = 1.4) sprint performances in this study. These results are similar to those reported by Darrall-Jones et al., (2016) who used Brower Timing Gates to assess the reliability of adolescent rugby players sprint performance. Darrall-Jones et al., (2016) found %CV for 10-metre, 20-metre and 30-metre sprint performance to be 3.1%, 1.8% and 2.0% respectively. Research by Morris et al., (2018) has found that adolescent footballers in pre-PHV and circa-PHV maturation groups improved their 30-metre sprint performance by 0.06 seconds over one full competitive season. In the current study the TE of the 30-metre sprint test was also 0.06 seconds. This suggests it is possible that the pre-PHV and circa-PHV adolescents in the current study could improve their 30-metre sprint performance by a value at least equal to the TE of the test. However, Morris et al., (2018) reported that post-PHV adolescent footballers 30-metre sprint performance decreased by 0.02 seconds. Morris et al., (2018) suggests that as post-PHV players are exposed to higher loads as they progress through an elite youth academy and the accumulation of fatigue over the course of a season limits the development of sprint performance. Furthermore, a change of 0.02 seconds is within the TE established in this study for 30-metre sprint performance and therefore could not be deemed as a true change in performance. The maturation status of the players in the current study ranged across both circa-PHV and post-PHV maturation groups (0.8 ± 0.9 years). Although results of this study add to the rationale that sprint performance tests are reliable in adolescent footballers, further research is required to establish the magnitude of changes in sprint performance, in different maturation groups, over a longer period of time. This will provide practitioners with a better understanding of the usefulness of the sprint performance test to monitor speed in adolescent footballers, across different maturation groups.

When analysing the sprint performance data of the current study, it was clear that both relative and absolute reliability increase as distance increases. This has also been reported in a previous reliability study using Brower Timing were the %CV of 10-metre sprint performance (2.0) was higher than the %CV of 30-metre sprint performance (1.8) of adolescent rugby players (Waldron, Worsfold, Twist & Lamb, 2011). A suggested reason for improved reliability with increased sprint distance is that athletes tend to lean forward during the acceleration phase of a sprint. Therefore, there is a risk an athlete may cut the starting light beam early with an upper limb leading to an inaccurate first split time (Darrall-Jones, Jones, Roe & Till, 2016). Furthermore, between trials, there may have been slight differences in the size of the horizontal force initially produced by the players. These slight differences may have affected the reliability of 5 and 10-metre sprint performance as the application of horizontal force is a key component of the acceleration phase (Buchheit et al., 2014). Overall, the results of this study suggest that 30-metres is the most reliable distance to assess the sprint performance of adolescent footballers.

Although all physical performance tests produced acceptable levels of reliability, the usefulness of each test was found to be *marginal.* This was due to the TE of each test outcome being larger than the SWC. Therefore, if a players' test score increased or decreased by a value equal to the SWC, we are not able to determine if this change is real as the change is within the noise (TE) of the test. This is the first study to determine the usefulness of an eccentric hamstring strength test and isometric adductor strength test using the Nordbord and Groinbar, respectively. However, the usefulness of a sprint performance, using Brower Timing Gates, has previously been found to be *marginal* when used in adolescent rugby players (Darrall-Jones, Jones, Roe & Till, 2016). To combat the fact that the TE of a performance test is greater than SWC, Hopkins (2000) proposed a method whereby the changed score of an athlete is plotted, with TE as error bars, against the SWC. If the changed score and its error bars (TE) are out with the SWC, practitioners can say with 75% probability that this is a clear change (Hopkins, 2000). This will give practitioners key information on the practical significance of a change in physical performance and this method is currently being used in an applied setting (Duthie, Pyne, Ross, Livingstone & Hooper, 2006; Pyne, 2003).

As all three trials of the physical performance tests were completed within one training micro-cycle, it was unlikely that any changes in scores between trials would have been larger than the noise of the test. Knowledge on the minimal change in a test score required to be deemed real is essential to applied sport scientists. With results of the current study in mind, changes in performance of adolescent footballers must be greater than the TE and not the SWC of the test before the change can be deemed real. Further research is required to quantify the effects different football scenarios such as; an in-season training period, a competitive match and a week of training cessation, have on measures of lower body strength and speed. It is possible that these scenarios may induce changes in eccentric hamstring strength, isometric adductor strength and sprint performance test scores, greater than the TE established in this study. Therefore, this information could aid the monitoring process and the periodisation of training schedules of adolescent footballers (Buchheit, Spencer & Ahmaidi, 2010).

In conclusion, this study has quantified the relative and absolute reliability of eccentric hamstring strength, isometric adductor strength and sprint performance tests in adolescent footballers. Results of the current study suggest that eccentric hamstring peak force and peak torque; long lever measures of isometric adductor peak force and 30-metre sprint performance are the most reliable measures of physical performance in adolescent footballers. Although test usefulness was found to be *marginal* for all performance outcomes, practitioners could follow the guidelines proposed by Hopkins (2000). The change score of a test, using TE as error bars, can be plotted against the SWC to assess if the change score is real (> TE) or of practical significance (> SWC). This study provides the rationale for the potential use of these physical performance tests as monitoring tools in adolescent footballers. However, further research is required to assess the changes in test scores over acute and chronic periods of time as well as various football scenarios.

Chapter 4 – Quantification of In-Season Load and Associated Changes in Lower Body Strength and Speed in Adolescent Footballers.

Introduction

It is common practice in many countries, Including Scotland, for adolescent players to be identified by professional clubs as having the potential to become a senior professional footballers. The talent identification process starts from an early age with players as young as 8 years old being recruited into youth academes (Ford et al., 2020). The players who are invited to join the clubs' pro-youth academy have the opportunity to train and develop in an elite environment. This is in contrast to 'grass roots' players who participate in football at a non-elite level. Adolescent players who train and play with a pro-youth academy are commonly exposed to higher training and match loads, compared to 'grass roots' players, to accelerate talent development (King, 2017). However, at present our understanding of the physiological responses associated with such increases in training volume amongst adolescent players is poorly understood.

Accordingly, monitoring the training and match load of adolescent footballers is an important area of research. In chapter 3, measures of eccentric hamstring strength, long lever isometric adductor strength and 30-metre sprint performance were found to have typical error (TE) values of 19.9 Newtons, 12.7 Newtons and 0.06 seconds, respectively. Whether this degree of sensitivity relates to changes associated with training and match play is unknown. If, following training and match play, changes in lower body strength and speed are greater than the TE, practitioners may benefit from collecting this data at various points throughout the season to add to their understanding of how players are responding to the prescribed load. As such, there is growing interest in the load that players experience at different stages of the season and what effect this load has on different physical capabilities (Malone, 2014).

Muscular strength is an important physical quality in adolescent footballers as many changes of direction occur during a match which require forceful contractions of the musculature of the lower body, whilst trying to maintain balance or protect the ball under pressure (Stolen, Chamari, Castagna & Wisloff, 2005). Despite this, relatively little research is available that quantifies changes in local muscular strength in adolescent footballers following training and match play. Speed is an important physical quality in match situations, such as beating an opponent to a loose ball (Haugen, Tønnessen, Hisdal & Seiler, 2014). Research has shown that linear sprint performance of adolescent footballers takes 48-hours to return to baseline post match (Rampinini et al., 2011). In contrast, Rowsell et al., (2009), reported that adolescent footballers were able to maintain their speed after participating in four matches in four consecutive days. Therefore, further research is required to establish the effects of a match on adolescent footballers' linear sprint performance. Monitoring load and physical responses on a daily basis will give coaches and practitioners an indication of what modifications, if any, need to be made to the structure and content of training in order to optimise player performance and physical fitness (Djaoui, Haddad, Chamari & Dellal, 2017). During the in-season, if load has led to reductions in lower body strength or speed, greater than the TE of the test, this would suggest that the load being placed on the player is having a real change on performance. Whether this change is desired, for example where physiological adaptation is the aim, or not, in instances where performance is trying to be maintained, will guide how subsequent training is scheduled.

As adolescent players are required to play at least one match per week, it is important load is periodised to minimise fatigue and maximise player readiness (Malone et al., 2015). Therefore, practitioners often test players physical capabilities, such as lower body strength and speed, to assess individual responses to training and match load. Methods of monitoring lower body strength and speed must be reliable and sensitive to the daily variations in load (Thorpe et al., 2016; Fitzpatrick, Akenhead, Russell, Hicks & Hayes, 2019) if they are to be useful to the coach and practitioner. Methods that can be used to monitor changes in lower body strength and speed in response to load were reported in chapter 3. Previously in this thesis, the reliability of 5-metre, 10-metre, 20-metre and 30-metre linear sprint performance tests were quantified in adolescent footballers with 30-metres being the most reliable (ICC = 0.94, %CV = 1.4, TE = 0.06 seconds). Despite having high levels of reliability, there is little research that quantifies the perturbations in 30-metre sprint test performance, following a period of training and match play.

The Nordbord and Groinbar are used to assess the strength of the hamstring and adductor muscles, respectively. The reliability of both has been established in chapter 3. Measures of peak force in the hamstring muscles were found to have *very high* relative reliability (ICC = 0.87 – 0.88), *good* absolute reliability (%CV = 7.2 – 8.0) and a TE of 19.9 ± 11.0 Newtons. Measures of peak force in the adductors from a long lever testing position were also found to have *very high* relative reliability (ICC = 0.84 – 0.85), *good* absolute reliability (%CV = 8.1 – 8.6) and a TE of 12.7 ± 6.3 Newtons. As tests of muscular power, such as CMJ height, fail to detect true changes in performance in adolescent footballers in response to intense periods of training, (Malone et al., 2015; Fitzpatrick, Akenhead, Russell, Hicks & Hayes, 2019) tests of muscular strength may provide a better insight into the effects of load. However, there is little research that investigates the changes in eccentric hamstring strength and isometric adductor strength, despite both tests having high levels of reliability.

As well as a lack of research on the effects of training and match play on lower body strength and speed, there is little information available on what happens to these physical qualities when adolescent players stop training. In this authors experience, breaks in training during the in-season are unavoidable in adolescent football due to players going away with their families during the school holidays (e.g. Easter and Christmas) which can cause players to miss up to two weeks of training and match play. This can cause disruption, even in a well planned training schedule. Previous research by Joo (2016) found that a one week cessation of training for well-trained adult players can lead to significant reduction in repeated sprint performance. However, agility, intermittent aerobic endurance and 30-metre sprint performance were unaffected by the one week cessation of training. The effects a cessation in training has on adolescent players is not so clear and could be researched more to enable practitioners to make informed decisions on when best to load players to accommodate for these breaks in training.

There are three objectives of this study; 1) monitor the daily load and subsequent changes in lower body strength and speed, in adolescent footballers, over a 4-week training period, 2) assess the changes in adolescent footballer’s lower body strength and speed from pre to 24 hours post match and 3) to assess the effects of a one week cessation of training on adolescent footballers’ lower body strength and speed.

Methodology

Experimental Approach to the Problem

Eccentric hamstring strength, isometric adductor strength and liner sprint performance, were measured in a group of adolescent football players, who attended the same pro-youth academy, pre, post and during a 4-week in-season training period. Each player was scheduled to participate in twelve training sessions and four competitive matches throughout the 4-week training period. However, due to reasons out with the authors' control, only half of the training sessions and matches took place. Therefore, external and internal loads were quantified for six training session and two matches. Measures of lower body strength and speed were measured at the start of each new session. External load was quantified using GPS whilst internal load was monitored using, heart rate and ratings of perceived exertion. To quantify lower body strength and speed, each player completed a physical testing battery prior to each training session and match. Tests were completed in the following order throughout the duration of the study; eccentric hamstring strength; isometric adductor strength and 30-metre sprint. Figure 3 displays when each data collection point and training session or match took place. All data was collected during an in-season period were the focus of the training sessions was the continued development of technical, tactical and physical capabilities of the players.

Participants

Ten adolescent footballers (age: 15.1 ± 0.5 years; stature: 175.5 ± 4.6 cm; mass: 65.7 ± 5.9 kg; maturity offset: 1.7 ± 0.4 years) agreed to participate in this study. Researchers made no alterations to the players weekly training regime. Each player had been part of a pro-youth academy for a minimum of 3 years. At the start of the season each player, and their parent or legal guardian, within the youth academy gave written consent to their physical performance data being used for research purposes. The study was granted ethical approval by the School of Social Sciences at Heriot-Watt University conforming to the declaration of Helsinki.

Procedures

All testing took place approximately 30 – 60 minutes prior to the players' training session or match. The players in the study were completed two resistance training sessions per week, prior to their pitch based training session. All testing was completed prior to the scheduled resistance training. All players completed a standardised warm-up before testing that consisted of a raise, activate, mobilise and potentiate (RAMP) phase. This warm-up was used as it prepared the players for the high-intensity nature of testing, training and matches (Jeffreys, 2017). During baseline data collection, each player completed three physical performance tests in the following order; eccentric hamstring strength, isometric adductor strength and 30-metre sprint. Data collection took approximately 20 minutes.

Each player then had their eccentric hamstring strength, isometric adductor strength and liner 30-metre sprint performance tested, prior to each training session and match, for a 4-week training period. During this period, external load was quantified through the use of GPS whilst heart rate monitors and rates of perceived exertion were used to quantify internal load. After the 4-week training period, post study measures were collected prior to the start of the next scheduled training session. Identical procedures were used for pre, post and during study data collection.

Anthropometry & Maturity Offset

Prior to baseline data collection, anthropometric data was collected from all players for the calculation of maturity offset (Mirwald, G. Baxter-Jones, Bailey & Beunen, 2002). All procedures were identical to those described in chapter 3 of this thesis.

Eccentric Hamstring Strength

The Nordbord (Vald Performance, Queensland, Australia) was used to assess eccentric hamstring strength of the players. The procedures used were identical to those described in chapter 3. An average of the highest force produced by the right and left hamstrings was calculated after each data collection point and put forward for data analysis.

Isometric Adductor Strength

To assess the isometric adductor strength of the players, the Groinbar (Vald Performance, Queensland, Australia) was used. All testing was completed in long lever positions as results documented in chapter 3 found this testing position to be the most reliable. The procedures used were identical to those described in chapter 3. An average of the highest force produced by the right and left adductors was calculated after each data collection point and put forward for data analysis.

Sprint Performance

A linear sprint test was used to assess the speed of the players. Measuring sprint performance over a distance of 30-metres produced results with the best reliability compared to results produced at 5, 10 and 20-metre distances in chapter 3. Therefore, 30-metre sprint performance was assessed in this study. The procedures used were identical to those described in chapter 3.

External Load

GPS devices were used to quantify the external load throughout the study. The GPS system used was the Catapult Optimeye S5 (Catapult Sports, Melbourne, Australia). Each Optimeye S5 unit contained a 10 Hz GPS and an integrated 100 Hz tri-axial accelerometer (J. Wylde, B.C. Lee, Chee Yong & J. Callaway, 2018). Prior to data collection, each Optimeye S5 device was switched on and left outside, in an open area, for approximately 15 minutes in order to obtain satellite connection. Each Optimeye S5 device was then placed in a pouch, situated between the scapula, on the back of a custom made vest worn by the players. Each player used the same Optimeye S5 unit for the duration of the study to ensure intra unit reliability. Data was downloaded from the Optimeye S5 units after each use and analysed using Openfield software (Catapult Sports, Melbourne, Australia). Speed zone thresholds were set in accordance with Harley et al., (2010) who outlined thresholds for adolescent players, similar in age to the players in this study, from 10-metre flying sprint time. The following metrics from the GPS analysis were put forward for data analysis; total distance (TD) covered in metres and total distance covered at high speed in metres. High speed running (HSR) was defined as any distance covered at a speed greater than 5.04 ms^{-1} for more than 1 second.

Internal Load

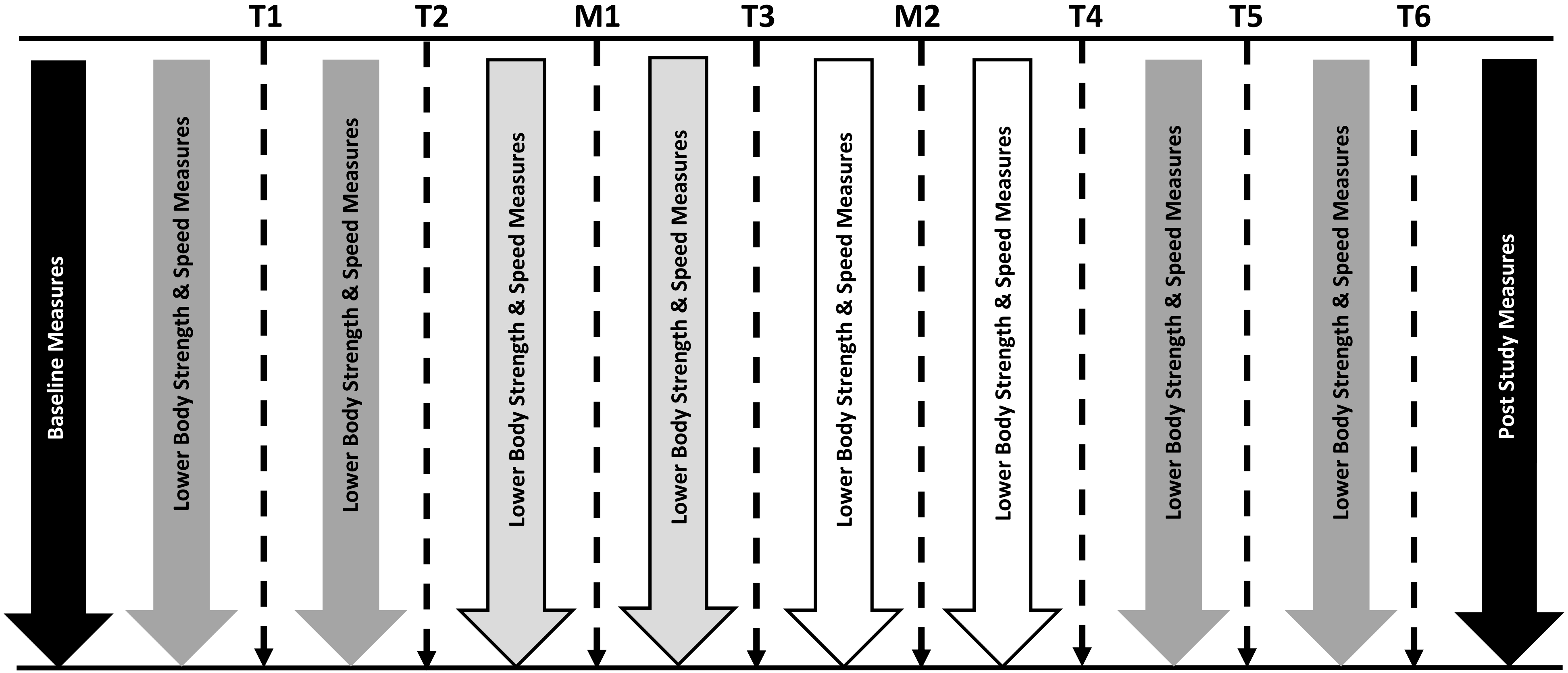
Heart rate monitors were used throughout the study to quantify internal load. Each player wore a heart rate monitor (Polar H1 transmitter, Polar, Kempele, Finland) on a coded heart rate strap that was housed inside the same custom made vest used to contain the Optimeye S5 units. The coded heart rate strap allowed heart rate data to be collected and stored wirelessly within the Optimeye S5 units. The heart rate monitor recorded a data point every 5 seconds. All data from the heart rate monitors was downloaded and analysed using Openfield software. Maximum heart rate (HR max) of the players was set based on the highest heart rate achieved during a match. Total time spent above 90% HR max during each training session and match was collected for all players and put forward for data analysis.

Internal load was also quantified using the s-RPE method. Using the CR-10 scale, s-RPE was recorded for all training sessions and matches completed during the study. A load value (AU) was then produced for each player by multiplying their RPE score by the duration of the training or match, as described elsewhere (Foster et al., 2001). Players verbally communicated their RPE to a tester after each training session and match. The players were encouraged to give their RPE score honestly and without peer influence. Previous research has found that there are no differences in RPE scores given by adolescent footballers when comparing scores provided immediately after training to scores provided 30 minutes after training (Fanchini, Ghielmetti, Coutts, Schena & Impellizzeri, 2015). Therefore, the players were asked for their s-RPE score at the cessation of each training session and match. All s-RPE data was recorded on a Microsoft Excel spreadsheet.

Statistical Analysis

All statistical analysis was performed on predesigned Microsoft Excel worksheets (Hopkins, 2015) and SPSS software (Version 25.0, IBM Corp., Armock, NY, USA). Shapiro-Wilk tests of normality were completed and showed all data to be parametric ($p > 0.05$). Change in mean (expressed as a percentage) with ± 95% confidence limits (CL) and effect sizes (ES) with ± 95% CL were calculated for all performance test outcomes over the 4-week training period. Effect size thresholds were set at 0, 0.2, 0.6 and 1.2 for *trivial*, *small*, *moderate* and *large* effects, respectively (Batterham & Hopkins, 2006). Effect sizes were also used to assess the differences in external load between each training session and match.

Figure 3. Timeline of data collection points throughout 4-week training period.



T1 = training session 1; T2 = training session 2; T3 = training session 3; T4 = training session 4; T5 = training session 5; T6 = training session 6; M1 = match 1; M2 = match 2; solid black arrows = data used to analyse changes lower body strength and speed after a 4-week training period; dark grey arrows = data used to analyse changes in lower body strength and speed between training sessions and matches; light grey arrows with black outline = data used to analyse the effects of a one week cessation of training on lower body strength and speed; white arrows with black outline = data used to analyse the effects of a match on lower body strength and speed.

Results

Total distance, HSR distance, time spent above 90% HR max, session duration and s-RPE was collected on eight occasions (six training sessions and two matches) during the 4-week in-season period. External and internal load metrics for each of the eight data collection points are displayed in Table 2. *Large* effect sizes (ES = 1.39 – 6.48) were reported for the changes in total distance covered between each training session and match. *Large* effect sizes (ES = 1.91 – 4.21) were reported for the changes in HSR distance between each training session and match apart from T5 and T6 where only a *trivial* change (ES = 0.08) was found.

Pre to post changes in lower body strength and 30-metre sprint performance over the 4-week period are depicted in Table 3. An increase in eccentric hamstring strength (13.9%; ES = 0.80), which was also greater than the TE, was found. An increase in isometric adductor strength (6.8%; ES = 0.54) was found however this was less than the TE. Sprint performance showed a *trivial* decrement (0.1%; ES = 0.03) which was less than the TE of the test.

Figures 4 and 5 display the changes in eccentric hamstring strength and isometric adductor strength in comparison to the changes in total distance covered during each training session and match. *Trivial* to *small* changes (ES = 0.02 – 0.24) in eccentric hamstring strength were found when comparing scores taken prior to the first training session (T1) to subsequent measures. Changes in isometric adductor strength ranged from *trivial* to *small* (ES = 0.06 – 0.29). None of the changes recorded were greater than the TE of the test for either eccentric hamstring strength and isometric adductor strength measures.

Measures of lower body strength and speed taken pre and 24 hours post match (M2) of the study were used for analysis. The second match was used for data analysis due to the fact that there was a one week cessation of training following the first match (M1) in the study. Results found a *trivial* decrease (-3.7%; ES = 0.23) in eccentric hamstring strength pre to post match. Change in isometric adductor strength was found to be *trivial* (0.9%; ES = 0.09). A *small* decrement in 30-metre sprint performance (0.9%; ES = 0.22) was also found pre to post match. All changes were below the TE of each respective test.

Physical performance test scores taken prior to the one week cessation of training (M1) were compared to those taken when the players returned to training (T3). Results found a *trivial* increase in eccentric hamstring strength (1.6%; ES = 0.08) and a *trivial* decrease in isometric adductor strength (-2.3%; ES = 0.16). A *small* improvement in 30-metre sprint performance (-1.1%; ES = 0.33) was found comparing results prior to M1 and T3. Changes in lower body strength and speed were smaller than the TE of each respective test.

Table 2. Load metrics (mean ± SD) for 4-week, in-season, training period (n = 10).

	Week 1			**Week 2**			**Week 3**			**Week 4**		
	T1 MD-3	**T2 MD-1**	**M1 MD**	**-**	**-**	**-**	**T3 MD-2**	**M2 MD**	**T4 MD+1**	**-**	**T5 MD+7**	**T6 MD+8**
Total Distance (m)	6590 ± 780	3947 ± 385	8175 ± 2657				5524 ± 331	8317 ± 3206	5135 ± 686		6229 ± 802	5048 ± 410
HSR Distance (m)	525 ± 267	83 ± 75	649 ± 249				258 ± 64	675 ± 308	180 ± 37		561 ± 228	522 ± 204
Time Spent Above 90% HR Max (mins)	5.57 ± 5.55	3.89 ± 4.91	15.25 ± 18.19				5.87 ± 3.99	20.96 ± 16.28	2.67 ± 5.71		8.04 ± 6.58	5.64 ± 4.97
Duration (mins)	90 ± 0	90 ± 0	79 ± 23				90 ± 0	71 ± 27	90 ± 0		90 ± 0	90 ± 0
s-RPE (AU)	648 ± 83	603 ± 95	672 ± 229				693 ± 85	647 ± 251	596 ± 82		711 ± 51	720 ± 73

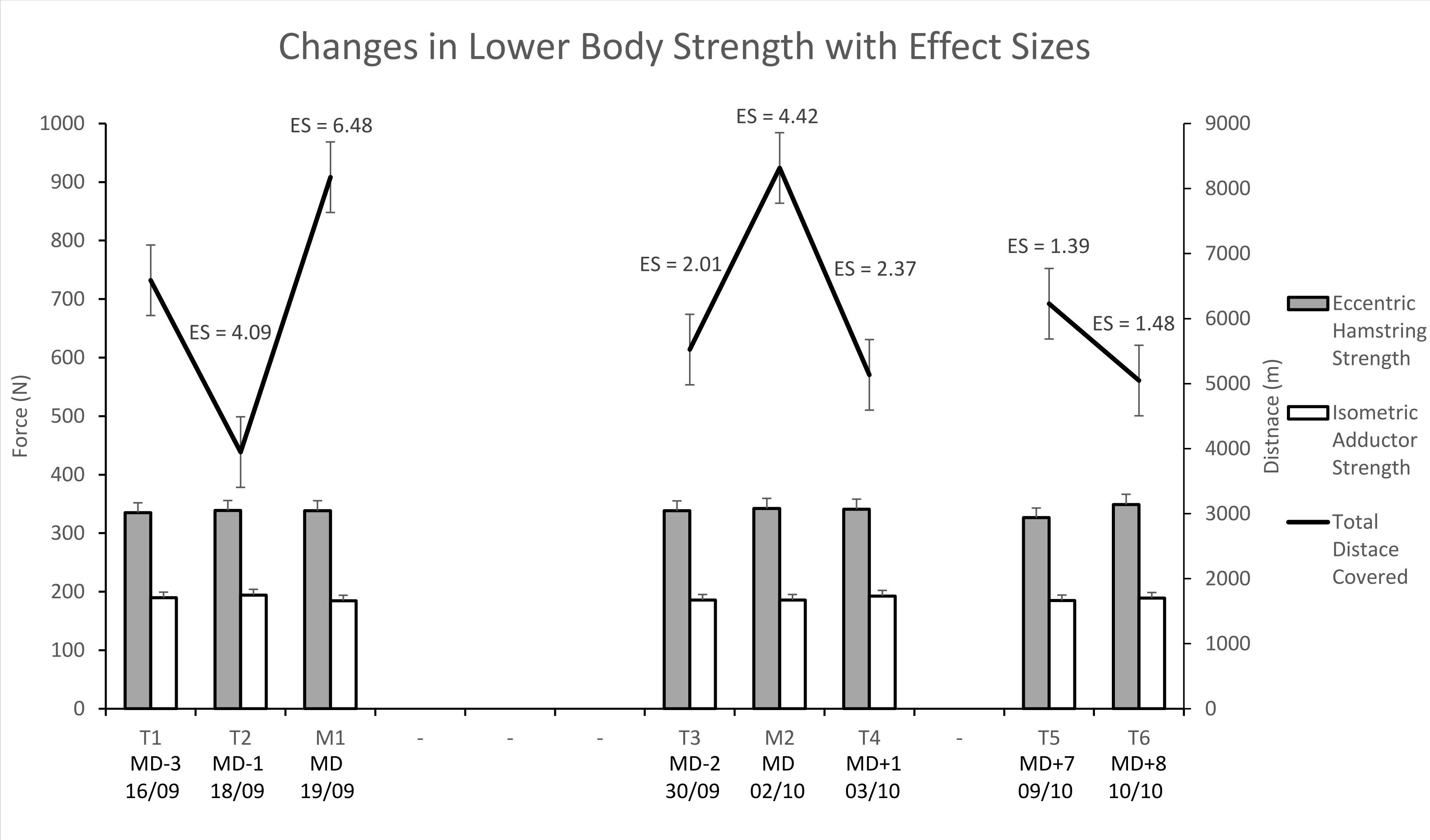
T1 = training session 1; T2 = training session 2; T3 = training session 3; T4 = training session 4; T5 = training session 5; T6 = training session 6; M1 = match 1; M2 = match 2; m = metres; mins = minutes; AU = arbitrary units; grey area = no training or matches.

Table 3. 4-week changes in lower body strength and speed (*n* = 10).

	Baseline Measure (Mean ± SD)	Post Study (Mean ± SD)	Typical Error (95% CL)	Change in Mean (%) (± 95% CL)	Effect Size (± 95% CL)
Eccentric Hamstring Strength (N)	311.9 ± 48.0	354.3 ± 45.0	19.9 (17.3, 23.6)	13.9 ± 7.9	0.80 ± 0.42
Isometric Adductor Strength (N)	176.3 ± 20.1	188.1 ± 18.5	12.6 (11.0, 14.9)	6.8 ± 6.7	0.54 ± 0.51
30-Metre Sprint (s)	4.59 ± 0.16	4.60 ± 0.16	0.06 (0.06, 0.08)	0.1 ± 1.1	0.03 ± 0.29

N = newtons; s = seconds.

Figure 4. Changes in lower body strength from the first training session (T1) measure (n =10).



ES = effect size of change in total distance covered between training sessions and matches.

Table 4. Effects of a match (M2) on measures of lower body strength and speed (n = 9).

	Pre Match (Mean ± SD)	Post Match (Mean ± SD)	Change in Mean (%) (± 95% CL)	Effect Size (± 95% CL)
Eccentric Hamstring Strength (N)	354.1 ± 49.0	341.2 ± 47.7	-3.7 ± 2.3	0.23 ± 0.15
Isometric Adductor Strength (N)	189.7 ± 17.1	193.5 ± 32.9	0.9 ± 9.4	0.09 ± 0.95
30-Metre Sprint (s)	4.59 ± 0.17	4.63 ± 0.17	0.9 ± 1.6	0.22 ± 0.40

Mean playing duration = 72 ± 27 minutes. N = newtons; s = seconds; pre match measures were recorded approximately 30 minutes prior to the start of the match; post match measures were recorded approximately 24 hours after the end of the match.

Table 5. Effects of a one week cessation of training on measures of lower body strength and speed (*n* = 10).

	Pre Cessation of Training (Mean ± SD)	Post Cessation of Training (Mean ± SD)	Change in Mean (%) (± 95% CL)	Effect Size (± 95% CL)
Eccentric Hamstring Strength (N)	342.2 ± 60.6	345.6 ± 47.2	1.6 ± 6.0	0.08 ± 0.29
Isometric Adductor Strength (N)	185.5 ± 23.6	181.6 ± 26.4	-2.3 ± 5.3	0.16 ± 0.37
30-Metre Sprint (s)	4.57 ± 0.17	4.52 ± 0.20	-1.1 ± 1.6	0.33 ± 0.41

N = newtons; s = seconds; pre cessation of training measures were recorded prior to M1; post cessation of training measures were recorded prior to T3.

Discussion

The aim of this study was to quantify the external and internal load and subsequent changes in lower body strength and speed over a 4-week in-season training period in adolescent footballers. Furthermore, changes in lower body strength and speed in response to; each individual training session and match, a single match and a one week cessation of training were investigated.

Acute and Chronic Changes in Lower Body Strength

After a 4-week training period, a *moderate* increase (13.9%) in eccentric hamstring strength and a *small* increase (6.8%) in isometric adductor strength were found. As this is the first study to analyse the changes in adolescent footballers' eccentric hamstring strength and isometric adductor strength over acute and chronic training periods, there is little comparable data in the literature. However, Nordbord measures taken at baseline in this study (311.9 ± 48 N) are similar to those found elsewhere for adolescent footballers (310.1 ± 54.3 N) (Sannicandro, Traficante & Cofano, 2019). There is currently no literature that uses the Groinbar to assess changes in adolescent footballers' adductor strength. The measure of peak adductor force recorded after the 4-week training period in this study (188.1 ± 18.5 N) is similar to the peak adductor force recorded in a cohort of senior footballers (189.8 ± 42.2 N) (O'Brien, Bourne, Heerey, Timmins & Pizzari, 2018). This could suggest that adductor strength is not trained in footballers due to the similarities in values produced by adolescents and adults. The increase in eccentric hamstring strength (42.4 N) found after the 4-week training period, was greater than the TE of the test established in chapter 3 (19.9 N) and can be deemed a real change. However, the increase in isometric adductor strength was smaller than the TE of the test established in chapter 3. A suggestion for the real change found in eccentric hamstring strength, but not isometric adductor strength, is the fact that there is a greater use of the hamstring muscles during training and matches. A players' hamstring has to act eccentrically to decelerate the tibia during rapid and forceful knee extensions that occur during sprinting and kicking (Delextrat, Gregory & Cohen, 2010). It is likely that a high frequency of eccentric hamstring contractions were experienced by the players, in this study, which led to the *moderate* increase in strength after the 4-week training period. Furthermore, previous research has found that both the Nordic curl exercise and sprint training can lead to significant gains in eccentric hamstring strength in adolescent footballers (Drury, 2019; Freeman et al., 2019). As the players were required to carry out three Nordic curls and two maximal sprints prior to each training session and match, it is possible that the procedures of this study may have caused the increase in eccentric hamstring strength, that was greater than the TE of the test.

Figure 4 show the changes in eccentric hamstring strength and isometric adductor strength following each training session and match. Despite the *large* variations in total distance covered during the 4-week training period, only changes of a *trivial* to *small* effect size were recorded for measures of lower body strength. Furthermore, the changes that occurred were smaller than the TE of the respective tests. This may suggest that the imposed load did not cause decrements in local muscular strength. However, Goodall et al., (2015) reported that knee extensor maximum voluntary contraction force significantly reduces by 9% after two maximal sprints in a cohort of adult intermittent sport athletes. A potential reason the same reduction in lower body strength was not found in this study, after each training session and match, is that adolescents are less susceptible to fatigue following high intensity exercise (Ratel, Williams, Oliver & Armstrong, 2004). Previous research has found that reductions in muscular strength, after a bout of muscle damaging exercise, to be less serve in adolescents than in adults. (Marginson, Rowlands, Gleeson & Eston, 2005). This due to adolescent's greater flexibility and ability to produce greater relative strength at long muscles lengths, leading to less overextension of sarcomeres during high intensity exercise (Marginson, Rowlands, Gleeson & Eston, 2005). Furthermore, as the adolescents in this study are accustomed to training and playing regular matches, it is possible that the repeated bout effect (McHugh, 2003) may have protected the lower body strength of the players in this study (Gibson, McCunn, MacNay, Mullen & Twist, 2018). The *trivial* to *small* changes in lower body strength recorded throughout the 4-week training period, were less than the TE of the test. Furthermore, the large TE of both tests was established in a very controlled environment. In a less controlled environment, such as the varying daily training loads reported, it is even less likely that a change greater than the TE of the test would have occurred. Therefore, it is suggested that the eccentric hamstring strength and isometric adductor strength tests are not sensitive enough to detect small, but possibly meaningful, true changes in strength on a daily basis. Therefore, practitioners must find an alternative method of assessing the effects of daily load on adolescent players lower body strength.

Acute and Chronic Changes in Speed

Over the course of a 4-week training period, the 30-metre sprint time of the players in this study increased by 0.1%. This increase was smaller than the TE of the test. *Trivial* changes (+ 0.02 seconds) in 30-metre sprint performance have been reported previously in adolescent footballers, who were also post PHV, after a full season of football training (Morris et al., 2018). Previous research has found that the maturation status of adolescent players can have an effect on their speed (McCunn, Weston, Hill, Johnston & Gibson, 2017). A *large* relationship between maturation status and 15-metre sprint performance has been found in players who are circa-PHV. Therefore, fluctuations in speed, in adolescent players of this age, are to be expected as they grow and develop. However, for players that are post-PHV there is a *small* effect of maturity status on sprint performance (McCunn, Weston, Hill, Johnston & Gibson, 2017). As the players in this study were post-PHV (1.7 ± 0.4 years), a change in sprint performance was not likely to occur over a 4-week training period. As sprint performance tests appear to lack the sensitivity to detect a true change in speed, coaches and practitioners must find an alternative method of assessing the effects of load on adolescent footballers' physical performance.

Effects of a Match on Lower Body Strength and Speed

The effects of a match on the eccentric hamstring strength, isometric adductor strength and 30-metre sprint performance of adolescent footballers were also analysed in this study. The physical demands of an adolescent football match have been reported by Carling et al., (2019) who found that the total distance covered, ranged between 6609 – 9950 metres and HSR distance ranged between 806 – 1253 metres. However, the effects of a single match on lower body strength and speed are less clear and is important given the prevalence of intensified period of competition in adolescent football (Arruda et al., 2015; Gibson, McCunn, MacNay, Mullen & Twist, 2018) In this study, there was no changes in lower body strength or speed greater than the TE of the respective tests, pre to post match with effect sizes no greater than *small*. Results agree with those of Wollin et al., (2018) who found adolescent footballers isometric adductor strength did not reduce by a value greater than the minimal detectable change after a match (Wollin, Pizzari, Spagnolo, Welvaert & Thorborg, 2018). However, measures of adductor strength were taken using a hand-held dynamometer from a short lever position, making comparisons with the present study difficult. Previous research has analysed the effects of a football match on the isometric hamstring strength of adolescent footballer's and found that it took 48 hours for strength to return to pre match values (Wollin, Thorborg & Pizzari, 2016). However, the same effect was not found in eccentric hamstring strength in this study. Post-match data was collected 24-hours post-match. This was a result of the players training schedule which was pre-determined by the club at the start of the season, making MD+1 the only available day for post-match data collection.

The HSR distance covered by the players during the match in this study was 675 metres. This is lower than the HSR distance covered by adolescent footballers in matches reported elsewhere (806 – 1253 metres) (Carling, Vieira, Barbieri, Aquino & Santiago, 2019). It should be noted that not all of the HSR thresholds reported by Carling et al., (2019) in the meta-analysis were calculated in the same way, a common issue when comparing external load values in adolescent players. As the hamstring muscles are required to work eccentrically during HSR (Delextrat, Gregory & Cohen, 2010), it is suggested that the high volume of HSR completed during a match would lead to a true reduction in eccentric hamstring strength 24 hours post match. This was not the case in this study and, suggests that the eccentric hamstring strength test was not sensitive enough to detect true a decrement in strength. Conversely, the volume of HSR completed during the match in this study (675 metres) may not have been enough to induce a reduction in eccentric hamstring strength, greater than the TE of the test, 24 hours post match. A *small* decrease in 30-metre sprint performance of the players was recorded 24 hours after the match.

This is in disagreement with Rampinini et al., (2011) who reported that it took 48 hours post match for the sprint performance of adolescent footballers to return to baseline values. The TD covered by the players in the Rampinini et al., (2011) study was higher in comparison to the players in the current study (11764 metres vs 8317 metres), as was the volume of HSR completed (2664 metres vs 675 metres). However, it should be noted that the threshold for HSR was higher in the current study (>5.04 ms^{-1} vs >4.17 ms^{-1}). This highlights the issue on interpreting match running performance in football as there is no consensus on how HSR thresholds should be calculated. The lower external load placed on the players may be the cause for the maintenance of sprint performance, pre to 24 hours post match. The lower external load reported in this study could be explained by the match outcome. The players in this study were playing an opposing team ranked in the top three of their respective league away from home. The players did not concede a goal until the final minute match. It has previously been reported that footballers who are pursuing a goal carry out more HSR, such as sprints into the oppositions penalty box to receive a cross (Andrzejewski, Konefał, Chmura, Kowalczuk & Chmura, 2016). It is possible that the players were content with holding their opponents to a scoreless draw and thereby limited the intensity and volume of running.

In this authors experience, and supported in the literature, it has been shown that adolescent footballers are often given the day off after a match or they engage in recovery strategies such as foam rolling, cold water emersion or wearing compression garments as opposed to participating in a training session (Kinugasa & Kilding, 2009). It is suggested that a day off and recovery strategies may not be necessary for adolescent footballers if the external load imposed by a match is similar to the values reported in this study, due to the *trivial* to *small* changes in lower body strength and speed pre to post match. With the SFA implementing Project Brave in order to “bring a greater focus to talent development and optimise playing opportunities,” it is suggested that elite youth academies could be using training time more effectively to develop adolescent footballers, especially given the limited time available in part-time training regimes to develop technical proficiency. However, research has shown that participating in a football match induces a mental stress on the players due to the need for sustained concentration and consistent decision making under pressure from an opponent (Nédélec et al., 2012). Having the day off after a match may allow players the time to recover psychologically. Further research is required to assess the psychological effects of a match on adolescent footballers.

Effects of Cessation of Training on Lower Body Strength and Speed

During this study, the players were given a week off from training and matches due to the belief of the academy director that it would allow them time to recover from previous training and matches. However, the desired outcome appears to have not been achieved. A *trivial* increase in eccentric hamstring strength, a *trivial* decrease in isometric adductor strength and a *small* improvement in 30-metre sprint performance were recorded pre to post cessation of training. These results are similar to those of Joo (2016) who analysed the effects of a short cessation of training in adult footballers. Results found no significant changes in 30-metre sprint performance or peak torques produced during knee flexion and extension at a range of different angular velocities (60° - 240°/s^{-1}). Results suggest that a short cessation of training has no beneficial or detrimental effects on the lower body strength and speed of adolescent footballers. However, there is research to suggest that a longer cessation of training may have a negative impact on adolescent footballers’ physiological capabilities. After a 4 week cessation of training, Melchiorri et al., (2014) found a significant reduction in maximum oxygen uptake (21.2%), peak aerobic (7.0%) and anaerobic (7.2%) running speeds. Although these physical qualities were not assessed in the present study, the results of Melchiorri et al., (2014) highlight the potential detrimental impact of a long cessation in training on running performance. Further research is required to assess the effects of a prolonged cessation of training on adolescent footballers' lower body strength and speed. Furthermore, although not assessed in this study, the psychological effects of a short cessation of training may provide a greater insight into its usefulness during the in-season. It is suggested that, adolescent footballers do not require a cessation of training during the in-season as results of this study have shown that there are no benefits to the lower body strength or sprint performance of the players. Allowing adolescent players these short breaks is further restricting the already limited training time to improve not only physical qualities but also technical and tactical skills. Professional senior footballers are exposed to higher training volumes and in order to optimally prepare adolescents for the increase in physical demands they will experience as they get older, unscheduled in-season cessation of training should be avoided where possible.

Conclusion

In conclusion, this study has highlighted the changes in the lower body strength and speed of adolescent footballers over a 4-week training period. The largest increase and only change greater than the TE of the test was found in eccentric hamstring strength. Changes in isometric adductor strength and 30-metre sprint performance were less than the TE of the respective tests, after the 4-week training period. Despite the *large* fluctuations in external load between training sessions and matches, only *trivial* to *small* changes in lower body strength occurred. This would suggest that the tests used in this study were not sensitive enough to detect true changes in local muscular strength on a daily basis. This study has also shown that a match has no significant effects on the lower body strength and speed of adolescent footballers. However, it should be noted that the match load experienced by the players was lower than match loads for adolescents reported elsewhere (Carling, Vieira, Barbieri, Aquino & Santiago, 2019). Furthermore, a one week cessation of training has been shown to have neither a beneficial or detrimental effect on lower body strength and speed. Practitioners should consider the results of this study when periodising training schedules and assessing the physiological development of adolescent footballers.

Chapter 5 – Discussion

Main Findings

This thesis has investigated the reliability of measures associated with eccentric hamstring strength, isometric adductor strength and linear speed in adolescent footballers and their usefulness in monitoring changes in performance following training and match play. The findings show that the Nordbord, Groinbar and 30-metre linear sprint test are reliable measures of assessing eccentric hamstring strength, isometric adductor strength and speed, respectively, in adolescent footballers. Unlike measures of isometric adductor strength and speed, eccentric hamstring strength increased by a value greater than the TE after a 4-week training period. Despite fluctuations in load (ES = 0.08 – 6.48) between training sessions and matches over the same 4-week period, no changes in lower body strength were reported between discrete exposures to training and/or match play. Measures of lower body strength and speed were unchnaged by a single match and a one week cessation of training.

The first aim of this thesis was to quantify the reliability of eccentric hamstring strength, isometric adductor strength and linear sprint performance tests in adolescent footballers. *High* levels of relative reliability (ICC = 0.87 – 0.89), *good* absolute reliability (%CV = 7.2 – 8.1) and a TE of 19.9 Newtons were reported during the eccentric hamstring strength test. This is the first study to document the reliability of the Nordbord, to assess eccentric hamstring strength, in adolescent footballers. Results agree with those of Opar et al., (2013) who found similar levels of reliability (ICC = 0.83 – 0.90, %CV = 5.8 – 8.5, TE = 24.6 Newtons) in adults. The Nordbord is a more accessible method of quantifying eccentric hamstring strength compared to alternative methods such as hand-held dynamometers which require tester skill and experience (Stark, Walker, Phillips, Fejer & Beck, 2011). Based on the results of this thesis, the Nordbord is a reliable method of assessing eccentric hamstring strength in adolescent footballers. Although the Nordbord was found to have high levels of reliability, no changes greater than the TE of the test were recorded when comparing measures taken between training sessions, pre to 24 hours post match or pre to post one week cessation of training. Therefore, despite the Nordbord being a reliable method to assess eccentric hamstring strength in adolescent footballers, the test may not be sensitive to changes that occur following training and match play. Similar findings were reported for the isometric adductor strength test where long lever measures of isometric adductor strength produced *high* levels of relative reliability (ICC= 0.84 – 0.85), *good* absolute reliability (%CV = 8.1 – 8.6), and a TE of 12.7 Newtons. Long lever measures were found to be more reliable than short lever measures. This is in agreement with Light and Thorborg (2016) who reported greater levels of reliability from long lever measures compared to short lever measures when using a hand-held dynamometer in adult footballers. A potential reason for this finding is the ease of standardisation in the long lever testing position compared to the short lever testing position (0° vs 60° hip flexion). Despite the high levels of reliability found during the long lever isometric adductor strength test, no changes greater than the TE of the test were found when comparing measures taken between training sessions, pre to 24 hours post match or pre to post one week cessation of training. Despite the Groinbar being a reliable method to assess isometric adductor strength in adolescent footballers, the test may not be sensitive to changes that occur following training and match play.

When assessing the reliability of a liner sprint test a distance of 30-metres produced the most reliable results (ICC = 0.94, %CV = 1.4, TE = 0.06 seconds) compared to distances of 5-metres, 10-metres and 20-metres. These results support those reported in adolescent rugby players where improved reliability over longer sprint distances was observed (Waldron, Worsfold, Twist & Lamb, 2011). This finding is likely due to the forward lean of the torso players adopted prior to accelerating. Due to this forward lean, there is a risk that the starting light beam may be cut early with an upper limb (Darrall-Jones, Jones, Roe & Till, 2016). The early cut on the starting light beam has the greatest effect on the first split time due to the short distance available to compensate for the false start. Additionally, slight differences in initial horizontal force produced by players may affect the reliability of shorter testing distances (Buchheit et al., 2014). As longer sprint distances take more time to complete there is a greater chance of changes occurring that are out with the TE of the test, assuming that the TE is the same for all sprint distances. However, no changes in 30-metre sprint performance greater than the TE of the test were recorded when comparing measures taken between training sessions, pre to 24 hours post match or pre to post one week cessation of training. Although linear sprint tests are reliable in adolescent footballers, the test may not be sensitive enough to detect changes that occur in speed, following training and match play.

Despite the eccentric hamstring strength test, isometric adductor strength test and linear speed test all having acceptable levels of reliability, none of the tests appear to be sensitive enough to detect true changes in performance in the acute period following training and matches. It was this author’s hypothesis that a reduction in lower body strength and sprint performance, greater than the TE of the test, would be found post training and matches but this was not found within the results. This may be due to the length of time between consecutive measures. As all measures were recorded approximately 30 – 60 minutes prior to the start of each training and match, at least 24 hours had passed since exposure to training and/or match play. Therefore, it is possible that 24 hours was sufficient time for the players to fully recover these physical qualities. It is possible that if follow up measures had taken place at the cessation of training and matches, real (greater than the TE) reductions in lower body strength and speed may have been recorded. The maintenance of lower body strength and speed 24 hours post training and matches found in the players in this thesis is in disagreement with previous research. Goodall et al (2015) reported a 9% reduction in knee extensor maximum voluntary contraction after two maximal sprints in adult footballers. A potential reason that similar reductions in measures of lower body strength were not found in the adolescent players in this study is that muscle damaging exercise appears to have a less serve effect on adolescents, compared to adults, due to their greater flexibility and ability to produce greater relative strength at long muscles lengths (Marginson, Rowlands, Gleeson & Eston, 2005). Rampinini et al (2011) reported that it took 48 hours post match for the speed of adolescent footballers to return to pre match values. This is in contrast to the results of this thesis where only a *small* decrease in 30-metre sprint performance was recorded 24 hours post match. The external load placed on the players during the match in this thesis (TD = 8317 metres, HSR = 675 metres) was lower than the external load of the match reported by Rampinini et al (2011) (TD = 11764 metres, HSR = 2664 metres) and a potential reason there was no change, greater than the TE, in speed pre to 24 hours post match. However, it should be noted that the HSR threshold in this study was higher than the one used by Rampinini et al., (2011) (>5.04 ms^{-1} vs >4.17 ms^{-1}). This highlights the issue of determining match running performance in adolescent footballers as there is no consensus on how speed thresholds should be calculated.

Although no changes greater than the TE of the test were reported in the acute period following each training session and match, there was a *moderate* increase greater than the TE (13.9%) in eccentric hamstring strength after a 4-week training period. A *small* increase (6.8%) in isometric adductor strength and *trivial* decrease (-0.1%) in 30-metre sprint performance were also recorded but neither were greater than the TE of the test. A suggested reason for the increase in eccentric hamstring strength is the procedure that was carried out during the study. Each player completed three Nordic hamstring curls and two maximal sprints during eight data collection points throughout the 4-week study period. Recently, an increase in biceps femoris long head fascicle length has been reported when additional sprint training (16%) or Nordic hamstring curls (7%) are completed alongside regular training in adult footballers (Mendiguchia et al., 2020). Furthermore, it has been reported that the Nordic hamstring curl and maximal sprinting can lead to increases in eccentric hamstring strength in adolescent footballers (Drury 2019; Freeman et al., 2019). Therefore, it is possible that the procedures and testing protocol led to the increase in eccentric hamstring strength, greater than the TE, pre to post the 4-week training period.

During this thesis, the players were given one week off from training and matches as a result of the belief amongst coaching staff that it would allow players to regain peak levels of physical performance. However, when comparing levels of lower body strength pre to post cessation of training, only a *trivial* increase in eccentric hamstring strength and a *trivial* decrease in isometric adductor strength was recorded. A *small* improvement in 30-metre sprint performance was found after the one week cessation of training. Results show that a one week cessation of training had no beneficial or detrimental effect on lower body strength and speed in adolescent footballers. Based on these findings it is suggested that, during the in-season and from a physical performance perspective, short and unscheduled cessations of training should be avoided as there is no benefit and adolescent players could be missing out on training that improves their technical and tactical skills.

Strengths & Limitations

Chapter 3 is the first study to quantify the reliability of the Nordbord and Groinbar to assess eccentric hamstring strength and isometric adductor strength in an adolescent population, despite both procedures being commonplace in the field. Based on these results, practitioners can use the Nordbord and Groinbar in a cohort of adolescent footballers with knowledge of the thresholds that determine real change. Furthermore, practitioners are now aware that the Nordbord, Groinbar and 30-metre sprint performance tests do not detect changes in lower body strength and speed, 24 hours post training or match play, in adolescent footballers.

Despite these strengths, this thesis is not without limitations. In chapter 4, the players completed resistance training prior to each football based training session. Unfortunately, the researchers had no control over the programming of the resistance training and therefore were unable to use an appropriate method to quantify the load, either objective or subjective, imposed on the players. Previous research has shown that a period of resistance training can lead to improvements in lower body strength and speed in adolescent footballers, similar in age to those in this thesis (Christou et al., 2006) which may explain the improvement in eccentric hamstring strength observed. Furthermore, the organisation of the 4-week training period was a limitation to the second study in this thesis. The players were originally scheduled to complete twelve training sessions and four competitive matches during the 4-week training period. However, half of the training sessions (n = 6/12) and matches (n = 2/4) were cancelled or rescheduled, due reasons out with the researchers' control. Therefore, the 4-week training period, used in this thesis, was different to that originally planned and which would be considered a normal meso cycle for the players. If more match data had of been collected, it may have been possible to analyse the matches out with the contextual factors that influence load such as, score line, opposition and tactics. Additional match data would have also given the author the opportunity to report the training load data as a percentage of match load. It was not possible to do this with accuracy with only two matches worth of data. Furthermore, due to the high level of variability in football tactics, score lines and opposition, even a whole seasons worth of match data may not have allowed for accurate comparisons to different match outputs. The small sample size in the second study of this thesis can also be considered as a limitation. This is specifically true for the analysis of the pre and post-match data as some players played less of the match than others. This made analysis of match load difficult considering there was only two matches played throughout the duration of the study.

Future Areas of Research

Measures of lower body strength and speed did not change by a value greater than the TE of the respective tests, 24 hours post training and match play. However, previous research has found that measures of lower body strength and speed are reduced immediately post training and match play in adolescent footballers (Rampinini et al., 2011; Wollin, Thorborg & Pizzari, 2016). Therefore, further research is required to establish at what point do lower body strength and speed return to pre training or match values in adolescent footballers. It is possible adolescent players may only need 12 hours after a training session or match to fully recover their lower body strength and speed, which has implications for the scheduling of fixtures during intensified periods of competition (Gibson, McCunn, MacNay, Mullen & Twist, 2018). It is thought that the testing battery, that included Nordic hamstring curls and maximal sprinting, completed by each player led to the *moderate* increase (13.9%) in eccentric hamstring strength over the 4-week study period. However, it cannot be stated for certain that this was the true cause of the increase, as the players also completed regular training and matches throughout the study. Therefore, further research is required to assess the effects of the 4-week testing battery, without regular training and match play, on the eccentric hamstring strength of adolescent footballers. A one week cessation of training in this thesis produced no changes in the lower body strength and speed of the players. However, Melchiorri et al., (2014) reported that a 4-week cessation of training led to significant reductions in the maximum oxygen uptake, peak aerobic and anaerobic running speeds of adolescent footballers. Further research is required to assess if a 4-week cessation of training, a time course representative of the off-season period, would have the same effects on adolescent players lower body strength and speed. Due to the variation in speed thresholds that are used to quantify the amount of HSR that adolescent players are exposed to during training and matches (Carling, Vieira, Barbieri, Aquino & Santiago, 2019; Rampinini et al., 2011), it was difficult to compare results of this thesis to the literature. Therefore, further research is required to establish a uniform method of setting speed thresholds, for adolescent footballers, that is of use to all practitioners working in the field.

Practical Applications

The Nordbord, Groinbar and 30-metre sprint test are reliable methods of assessing the eccentric hamstring strength, long lever isometric adductor strength and speed of adolescent footballers. Therefore, practitioners can use the thresholds established in this thesis to evaluate if differences in lower body strength and speed are real changes. Despite having acceptable levels of reliability, it appears that measures of lower body strength and speed are not sensitive enough to detect potential changes in performance 24 hours after a training session or match. Practitioners should consider if testing lower body strength and speed, to quantify the effects of the previous training or match load, is best conducted immediately after the cessation of a training session or match, especially in instances where training is conducted in the evening and on school nights. Isometric adductor strength and speed did not change by a value greater than the TE after a 4-week training period. Therefore, practitioners should consider if assessing these measures is necessary or time efficient on a monthly basis. It may be that a longer training period (e.g. 3 months) between testing sessions would produce changes greater than the TE when assessing lower body strength and speed in adolescent footballers and allow a more effective analysis of the dose response relationship. More data is required to establish the time course of real change in these measures and how much load is required to achieve notable change. The match load placed on the players in this thesis did not lead to real changes in lower body strength and speed, 24 hours post match. Therefore, match load should be analysed in order to make an informed decision on the content and scheduling of subsequent training sessions. If match load is similar to values reported in this thesis, a recovery session may not be entirely necessary in adolescent footballers due to the maintenance of lower body strength and speed, pre to 24 hours post match. Furthermore, a one week cessation of training was found to have no beneficial effects to the lower body strength and speed of the players. It is suggested that cessation of training should be avoided during the in-season in order to allow adolescent players a greater chance to develop their technical, tactical and physical skills by maximising training opportunities.

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